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Oriented Multi-Body System Virtual Prototyping Technology for Railway Vehicle

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1. Introduction

1.1 Railway vehicle virtual prototyping

In recent years, knowledge-based new product competition has become the mainstream of manufacturing competitiveness. As an important way to simulate various problems of complex mechanical systems, virtual prototyping technology is being widely used. It supports concurrent engineering and emphasizes the overall product performance, and strives to simulate the product function and behavior. Based on considering the overall product performance in three-dimensional CAD and its following function modules, virtual prototyping does the innovative design and informs a digital prototyping which do not depends on the physical prototype.

Virtual Prototyping (VP) is a new product design method generated in the recent 20 years. Based on computer simulation, VP embodies not only the product's innovative design but also the product's risk-free digital test, especially suiting for high cost trial production of complex mechanical system development. The main elements of VP are: virtual prototype model - virtual test analysis - virtual prototype evaluation (qualitative and quantitative). VP embodies the global optimization process which is based on computer simulation and aims to get more realistic products. It supports "Top-to-Down" design approach. The main techniques of VP ---- CAX, multi-body system modeling and analysis, simulation, optimization, visualization and VR technology are used to get a digital prototype with optimized performance, thereby the development costs and the reliance on physical prototypes are reduced, product qualities are improved, and time-to-market is accelerated.

Railway vehicle system which belongs to complex mechanical system areas is composed of mechanical, electrical, active control and drive systems (power distributed EMU), and its main part is mechanical systems. The quality of vehicle performances is the key problem of the vehicle product development. Based on the railway vehicle product design, especially the design results of the whole product machine, the performances include: dynamic performance, operational safety, aerodynamics, air-condition, strength and fatigue reliability. Therefore, it is inevitable to research and develop the railway vehicle virtual prototyping for advanced manufacturing technology.

It is also inevitable to research the railway vehicle virtual prototyping technique for the railway transportation equipment, especially for the high-speed, heavy haul train. The past railway vehicle product development mainly takes the following forms:

1. For the research methods, the traditional design embodies the serial, over-reliance on physical prototypes and over-focuses on local optimization of product characteristics, over-emphasizes on the structure itself, less stresses on the whole design features. As the increasing of railway vehicle speeds, these traditional design methods can not meet the performance requirements of high-speed vehicle, so a new performance design concept must be adopted which particularly emphasizes on the overall performance requirements under the high-speed conditions.
2. For the research process, the traditional design methods do not form a complete innovative product development system. Different railway vehicle models were designed by different research institutes, followed by the related performance analysis carried out by other different research units, then they were produced by relevant companies and tested to form the product at last. This has led to no systematicness in the product development process and a serious gap between design, performance analysis, manufacturing and testing. And analysis platforms and analysis models which impact the product performance are different. For example, the structural strength analysis did not use dynamic load spectrum from dynamics study to fatigue strength analysis for key components and structure, and did not consider the impact of railway vehicle movement and structure vibration from the air flow disturbance, and so on. So there are differences between research results and actual operating conditions which lead to railway vehicle running accidents. According to this situation, based on improving the various functional softwares of railway vehicles to establish integrated and intelligent performance design software platform, and form a unified computing methods and standards, combing traditional mechanical design, part strength analysis and product performance analysis in a design analysis platform to do visual design and overall performance design is very urgent.

Improving the speed of railway transport will not only bring issues such as safety, comfort, economy and environmental protection, but also result in a number of major scientific and technological problems. The most typical scientific and technical issues with speed are as follows:

- Air resistance problem - in the dense atmosphere, the aerodynamic drag is the cubic relationship to the rate of growth, so there is a reasonable speed value in terms of the track on the ground. Then, how to break this resistance barrier to further improve the ground speed of rail transport? Under the high-speed conditions, there are serious basic scientific problems to be solved, such as railway vehicle and air-coupled dynamic problem, air compressibility characteristics problem, and so on.
- Running noise problem - the main problem of high-speed railway vehicle is noise. Both the wheel-rail noise and aerodynamic noise need to be explored from the noise generation mechanism to the transmission mechanism. Vibration and noise reduction are the eternal scientific and technical issues.

With the increasing railway vehicle speed, safety, comfort, economy and environmental protection for high-speed railway vehicle are more and more important. Building the virtual prototype high-speed railway vehicle platform will provide strong technical support for researches arising from high speed.

Therefore, based on comprehensive analysis of related research fields, railway vehicle virtual prototype engineering research is carried out; the development and testing platform of railway vehicle virtual prototyping is established. Combined with the existing railway vehicle rolling test experiment bench, a hardware and software platform is formed which can make scheme decision and be easy to deal with three-dimensional CAX / DFX intelligent optimization design, a variety of integrated performance analysis (vehicle dynamics, aerodynamics, strength, fatigue reliability, etc.) and l dynamic running simulation of mutual behaviours. In the end, So it can enhance the innovative design for high-speed railway vehicle to a new level.

1.2 Research status of the railway vehicle virtual prototyping

At present, there are two levels in the virtual prototyping study. The first level is the development and manufacturing of the virtual prototype platform, i.e. the development of various software. There are three software development modes. First is the development of various functional modules software, such as Pro-E, Solidwork, Catia, UG, CAXA, etc; railway vehicle dynamics software: ADAMS/Rail, SIMPACK, NUCARS, VAMPIRE, DADS/Rail, etc; strength and fatigue analysis software: Ideas, ABAQUS, ANSYS, Fatigue, etc; fluid analysis software: FLUENT, StarCD etc; the work mainly depends on software companies to develop. The second is integrating various modeling and analysis software based on PDM, through the interfaces and PDM management (such as using collaborative management platform of Pro-E) to realize the concept of virtual prototyping-based software process, and design the experience and knowledge library, prototype library, model library, physical experimental data and analysis data repository. There has been some work on the re-development of existing software, but the analysis software itself has not been studied. The third level is developing a truly virtual prototyping platform to complete design and analysis in one software that does not need data transmission and conversion which is seamless connectivity. Such as Virtual-Lab from LMS company which co-operates with physical design software of Catia, mergers dynamics software of DADS, is seamlessly connected with ABAQUS, ANSYS (only finite element solver), and finally joins the advantages of fatigue and acoustic computing from LMS's own company to achieve a complete virtual prototype platform.

According to these studies, three main virtual prototyping platforms at present are as follows:

1. Virtual prototype platform architecture research based on simulation framework, mainly for spacecraft.
2. The core is CAX/DFX which is combined with other virtual prototyping platform analysis software, typically for Virtual-Lab from LMS which is a more versatile platform for virtual prototyping.
3. According to the industry needs and the concept of the virtual prototype, various analysis software were integrated based on PDM; some re-developments for acquiring the product solution are done. There are many such systems.

2. Layout of railway vehicle virtual prototyping

2.1 Overall plan

Complying with virtual prototyping technology, railway vehicle virtual prototyping intends to establish a digital development platform for railway vehicle products. According to the railway vehicle characteristics, the following factors should be considered:

1. Establish the railway vehicle product digital model. Based on three-dimensional CAD, establish the innovative design platform for railway vehicle products.

2. Integrate multi-domain prototype model. Based on three-dimensional CAD model, consider basic data of various characteristics of railway vehicle, such as physical information, assembly information, etc.
3. Take into account the integrality of the prototype model. Integrate seamlessly the multi-body dynamics environment and integrated model based on CAD, make dynamic automatic modeling and solving according to the CAD model, and build railway vehicle multi-body system with nonlinear dynamics simulation and computation.
4. Take into account the integrality of the prototype mode. Integrate seamlessly the integrated model and CAE analysis environment; analyze and simulate the structures, fatigue and the reliability performance for railway vehicle; simulate and calculate the model of airflow field and temperature field outside and inside the train.
5. Combine the virtual reality technology and build a virtual prototype test platform. Considering the simulation of human factor and hardware in the loop, the assessment analysis of railway vehicle virtual prototype should be built
6. Build the design platform of key components for railway vehicle, comprehensively evaluate the manufacturability to achieve the aim of railway vehicle virtual prototype based on CAX / DFX and optimize the design of railway vehicle virtual prototype.
7. In accordance with PDM principle, establish the data management platform of the entire system to build the system simulation management platform, and make the system an organic whole.

According to the specific case of railway vehicle virtual prototype, the program of establishing the "railway vehicle virtual prototype research and development platform" is shown in Fig. 2-1. The core part of the whole project should be achieved in high-speed local area network platform which supports concurrent engineering methodology and is composed of high-performance PC. The platform should be the overall situation to solve problems related to the global system. Considering the relationship of various parts of the virtual prototype, it can regulate and coordinate the running of various sub-systems, and share the information and resources to achieve the overall goal of railway vehicle virtual prototype.
Different constrained work is carried out concurrently on the basis of the management platform. There are mainly five major modules according to the product development process: PDM module, product research module, product performance analysis module, product virtual manufacture modules and product running simulation module, as shown in Fig. 2-1.

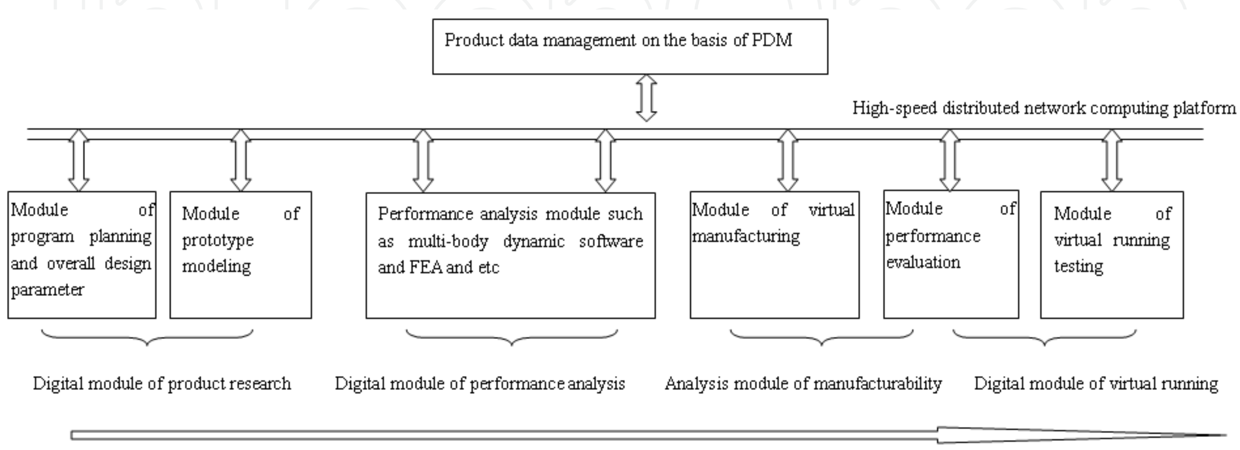


Fig. 2-1. Digitization process of the product research and manufacturing

In accordance with the above ideas, the concept of the platform for railway vehicle virtual prototype is shown in Fig. 2-2. Structure of this part is divided into four main sections:

1. Product digital design and simulation basis system
   This part is composed of distributed network running software and hardware, virtual prototype concurrent design and simulation systems, distributed database servers, clusters computer group and etc.
2. Product innovation design system based on three-dimensional CAD
   Around the mainstream 3D CAD software, a railway vehicle product innovation design platform which includes four major parts is built:
   a. Model design of product digitization
      This model is the basis for subsequent design and analysis. This section includes: product scheme design, design automation, serialization and modularization and optimization design, different model library for railway vehicles;
   b. Product modeling based on physical properties
      Interface the following performance and simulation, establish the interconnected middleware of CAD and CAE platform to achieve the model unity;
   c. Design oriented manufacturing
      This section is mainly designed for cost, assembly, processing techniques and other manufacturing characteristics. Evaluate the economy, manufacturability, assembly ability of products according to a comprehensive perspective to reduce the risk of trial and trial times for the final product optimization services. This section mainly includes: virtual assembly and virtual manufacturing;
   d. Product data management (PDM)
      This part mainly completes the integration management of the design and analysis of manufacturing data from database server.
3. Digital prototyping-oriented performance analysis
   Based on the above product digital description, mainly simulate the function, behavior and running environment of the products: railway vehicle multi-body dynamics analysis, multi-field coupling dynamic analysis and simulation, strength and fatigue reliability analysis of key parts, analysis and simulation of railway vehicle structural vibration noise, simulation of mode, brake and shock response, analysis and simulation of aerodynamics and air noise, co-simulation of multi-field coupling and etc.
4. Railway vehicle running simulation
   Combining with the digital model and various performance analysis results, the mixed digital simulation of the railway vehicle dynamic, which is a multi-domain environment coupled simulation, includes: railway vehicle running simulation and etc based on virtual reality technical.

Those four parts above form a more complete railway vehicle virtual prototype development platform. On this platform, PDM, concurrent simulation tools and platform are the linkage to achieve these functions. Fig. 2-3 is the data flow analysis for railway vehicle virtual prototyping engineering.

The part with thin red line means that exchange data is needed before data processing. From this it can be seen that the three-dimensional model is the entire data center of the system. The key processes of this part are: establish a reasonable railway vehicle database model and the database structure of the whole vehicle model, open the system to all data format; establish the database coordinating relationship between various databases; deal with concurrency control and collaboration issues between various database.

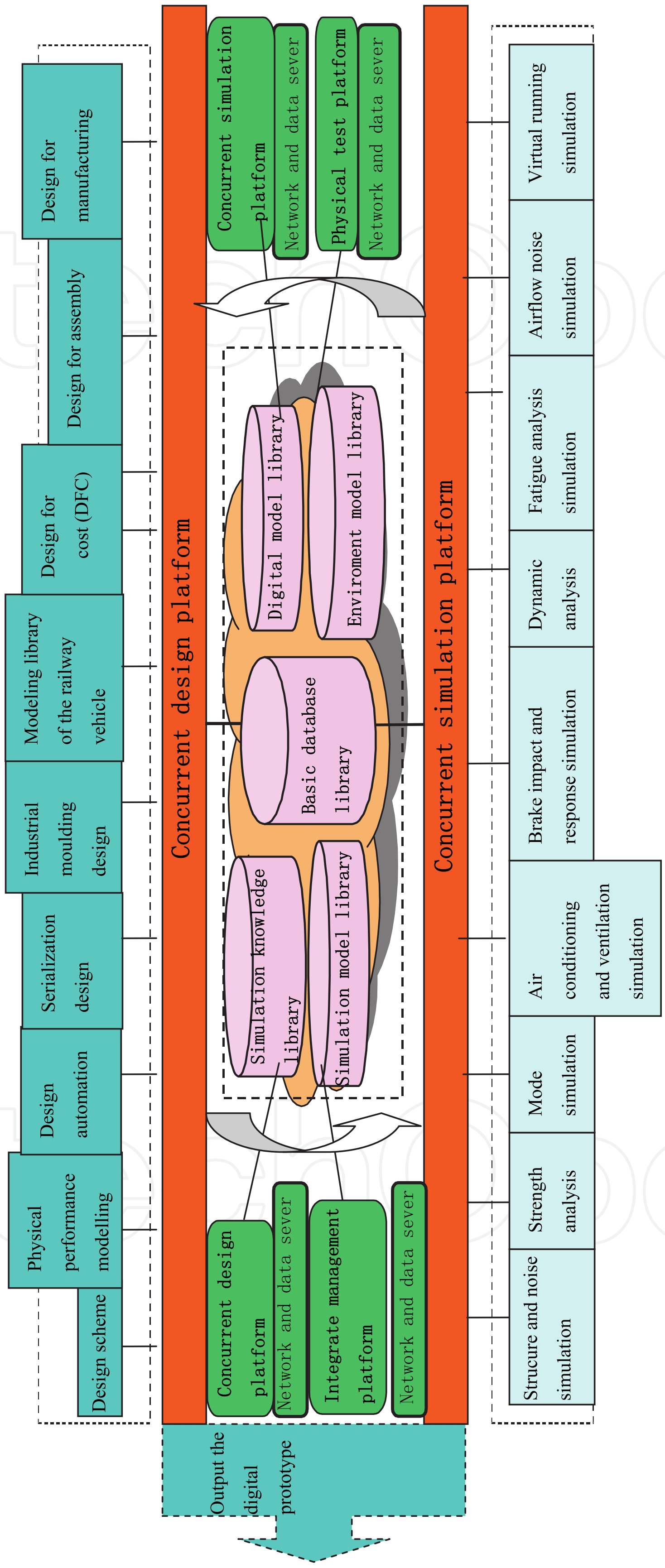


Fig. 2-2. Innovation system of railway vehicle virtual prototype

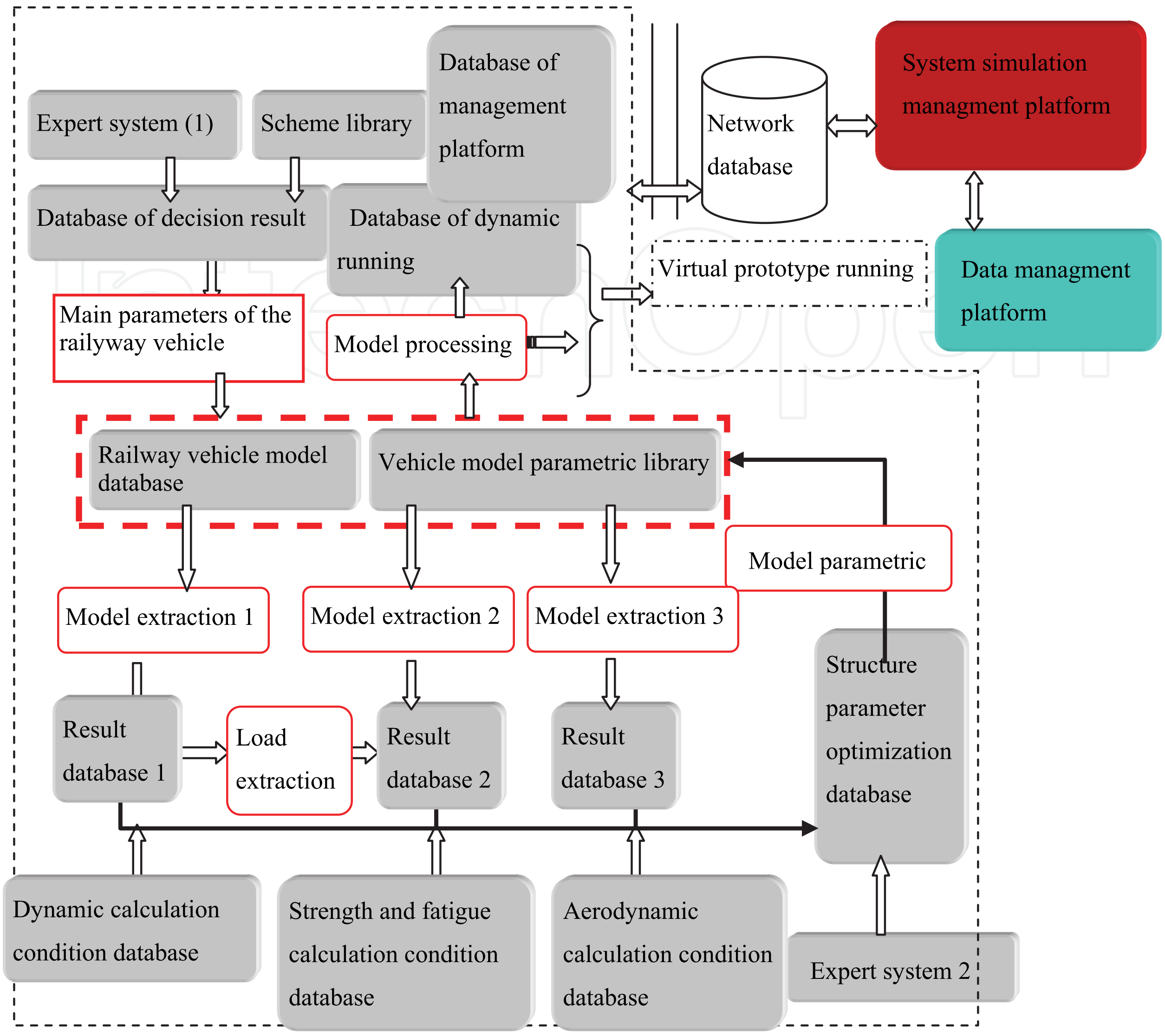


Fig. 2-3. Data flow analysis for railway vehicle virtual prototyping engineering

2.2 Innovative design platform for railway vehicle virtual prototyping

From Fig. 2-4, it can be seen that establishing a reasonable, reliable and adequate information model is the core of the entire system data processing. The model database is a complete virtual prototype model. The work will be done by the product design platform.

This section can rely on the function of three-dimensional solid modeling such as CAXA to improve itself, the specific functional requirements are:

1. Have all functions of generating three-dimensional solid model;
2. Generate the physical model and simplified model (simplified according to the requirements of the mechanical model) corresponding with three-dimensional solid model; plan the model according to the actual performance including materials, quality, mass center, surface area, volume, inertia moment, mechanical properties curve function, stiffness, composite calculation of main/sub-section and etc; classify the entities with performance characteristics in accordance with the similar principle.
3. Have the part assembly function, it is design for assembly (DFA) ,and can be combined in accordance with the model tree to generate a separate entity model, so that it has its

own physical property performance, for example: the change of the mass center, surface area, volume, inertia moment, materials composition and etc.

4. Establish constraint models of all kinds of components in accordance with the constraints. It should have the function of kinematics analysis which be able to detect interference, moreover can simulate the deformed elastic components.
5. Have parametric function which has both features and structural parametric characteristic to generate the parts automatically, and can modify the entity parameter manually or automatically according to the optimized result.
6. Geometric model must support the STEP standard and support design for manufacturing (DFM) to expand the virtual manufacturing;
7. Have the management function for all model databases and the whole vehicle database. Each component has a physical (including the simplified model) and geometric model sub-database. All model databases should be opened to all, and should have the function of automatic indexing.
8. All geometric and physical models must support the conversion with kinds of software interface and a strong re-development based on VC interface;

The architecture and data flow of this platform is shown in Fig. 2-4.

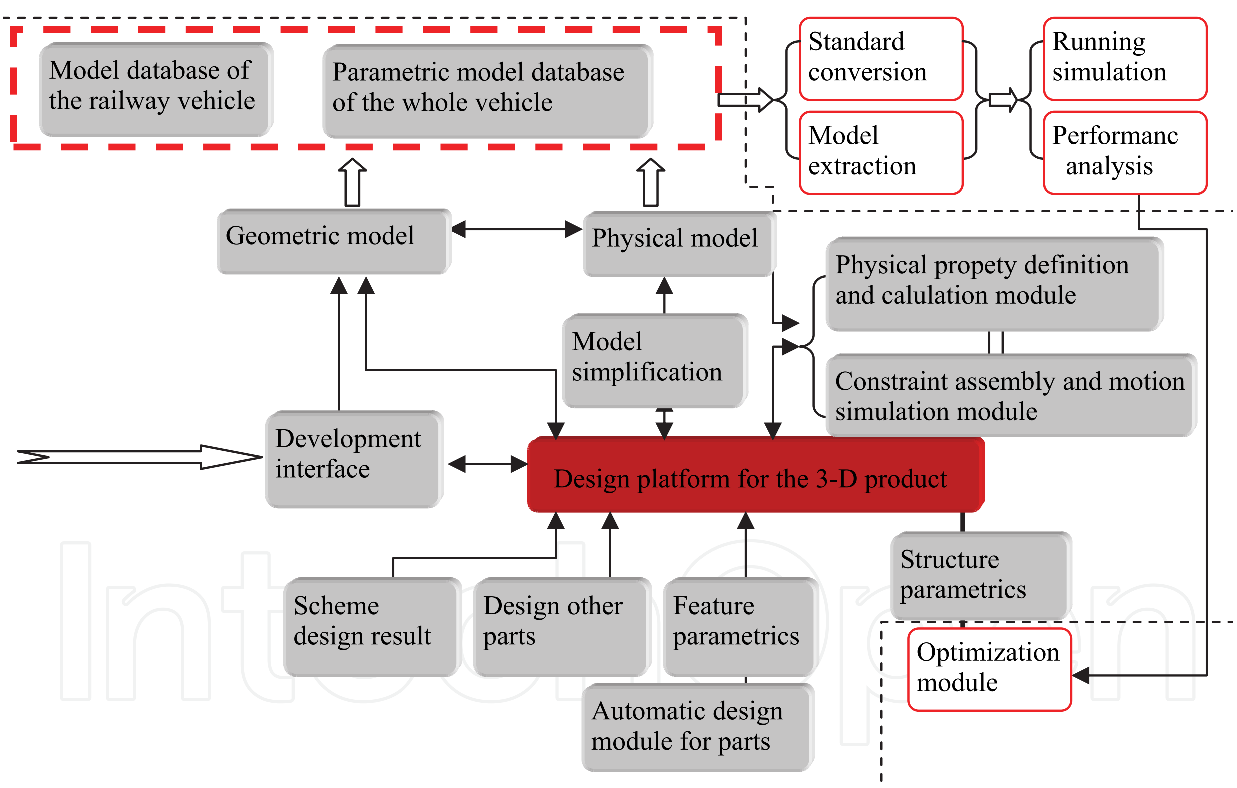


Fig. 2-4. 3-D design platform for railway vehicle oriented virtual prototyping

2.3 Performance analysis platform for railway vehicle virtual prototyping

Railway vehicle performance analysis is mainly composed by dynamics, intensity and fluid analysis, with the core dynamics based on meshing analysis. They are established on the basis of three-dimensional CAD digital model. The main ways to analyze railway vehicle are shown in Fig. 2-5.

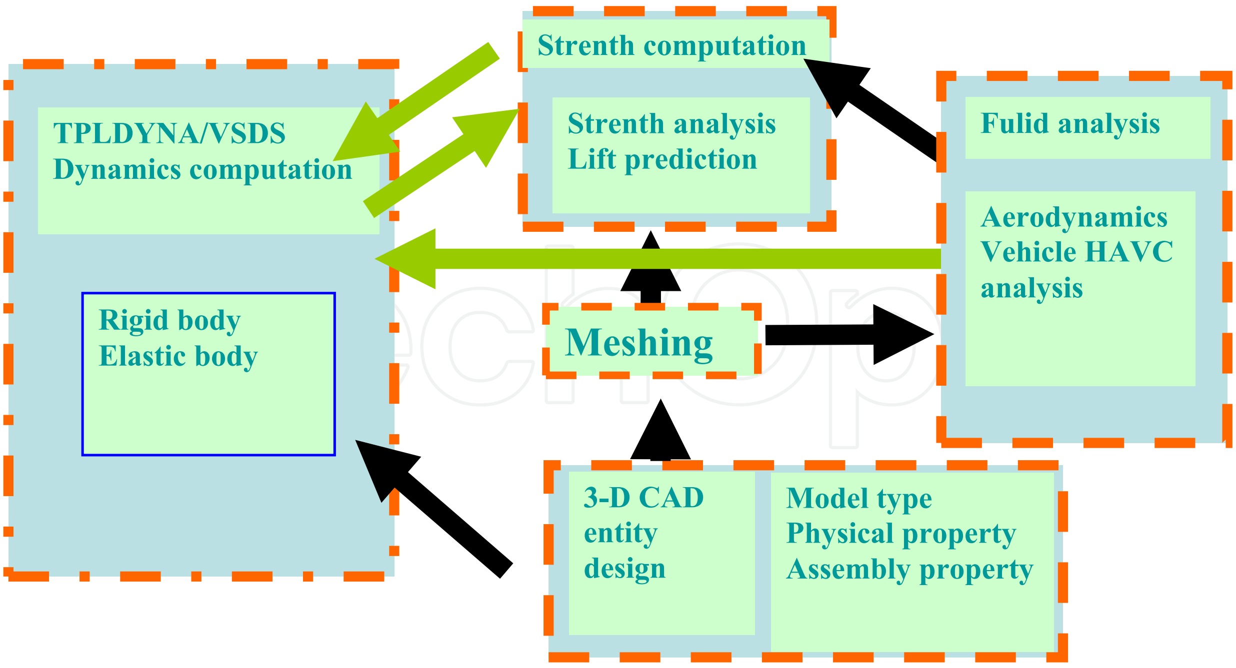


Fig. 2-5. Main ways to analyze railway vehicle

This platform integrates the railway vehicle parametric design and vehicle dynamics computation. Based on the railway vehicle dynamics simulation software, using multi-body system dynamics computation method and model database from entity CAD design, settle the model first, which includes error checking, feature and parameter identification and extraction to form the dynamic computation model. According to the simulation run line conditions, do simulation solution and analyze the three elements(safety, stability, comfortability) of the railway vehicle to obtain the critical instability speed, ride comfort, dynamic wheel-rail forces and other targets. The dynamic load and dynamic stress from simulation can be used for strength and fatigue reliability analysis. Send the result database is transferred to optimization design module to do parameters and structure optimization. The dynamic computational platform for railway vehicle is shown in Fig. 2-6.

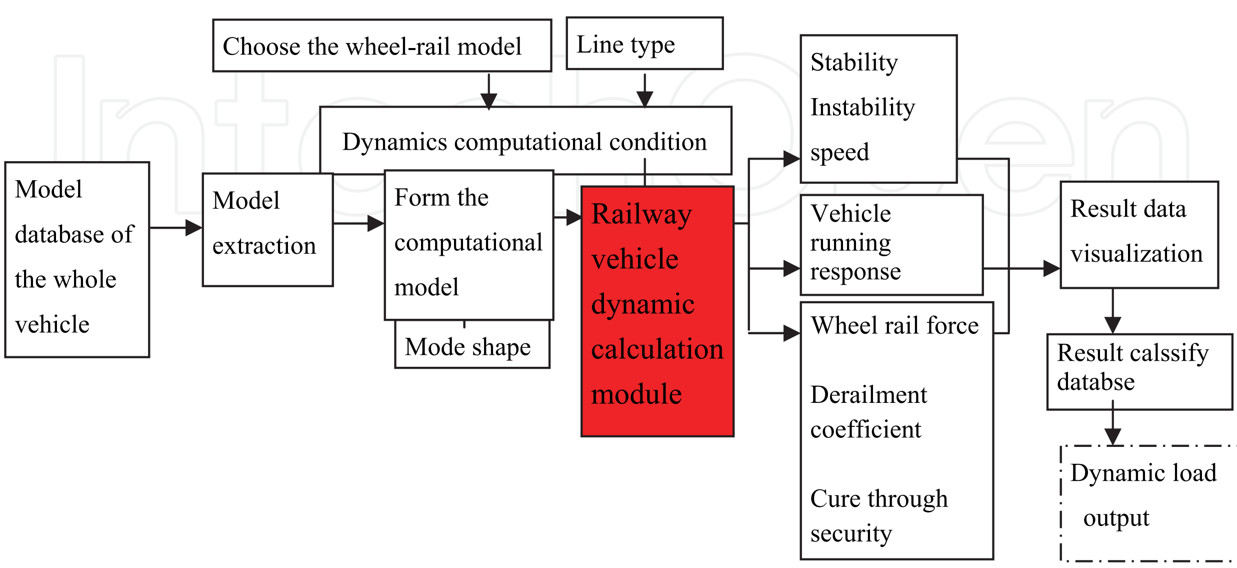


Fig. 2-6. Dynamic computational platform for railway vehicle

The key of this part is the extraction of the whole vehicle model database including entities simplification, combination, extraction of the physical properties, and extraction of coordinate location of the component and etc, with the requirement of using all data from the model database; In addition, data visualization and classification of the results also need interface development. This is the main context of this chapter.

2.4 Running simulation of the railway vehicle

The platform does the final integrated simulation of comprehensive test and evaluation to virtual prototype. Related tools are used to produce various effects, and the main task is to simulate various operating conditions of the vehicle to make clear people's understanding and awareness of the vehicle in the simulation loop. In other words, it means to regard people as an intelligent individual to do all performance testing of the virtual prototype, including: safety, comfortability, stability and so on. The core of this platform is virtual environment which has the following contents: vehicle LOD models, various result data form performance simulation computation, vehicle kinematics model, virtual reality interface device, a variety of effects tools (all kinds of dynamic simulation tools, brake tools, control simulation tools, etc.), virtual scene (bridges, tunnels, rail, the distance light scenes, etc.), control mathematical model, traction model, braking model and etc.

The key of this part is how to integrate these multi-dimensional information as a whole and simulate various properties of the railway vehicle virtual prototype, saving the dynamic test database as a certain prototype database ultimately. Running simulation of the railway vehicle is shown in Fig. 2-9.

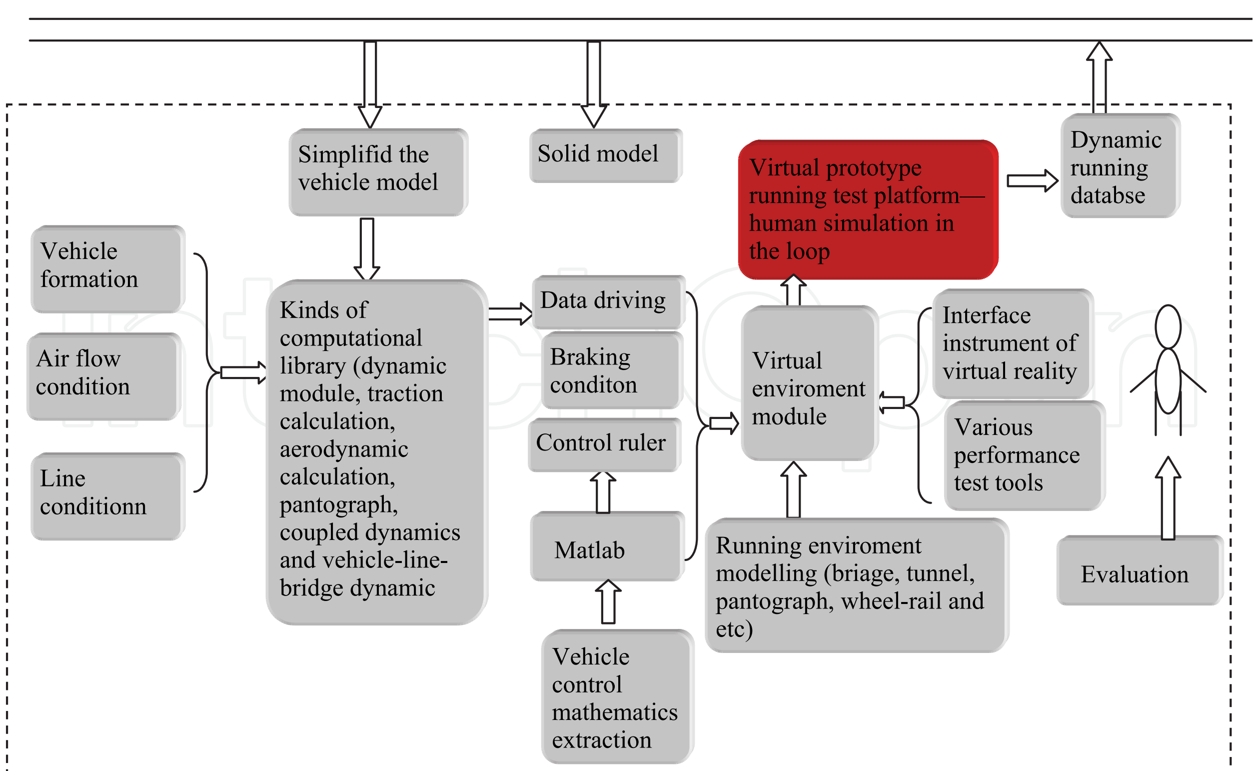


Fig. 2-9. Running simulation of the railway vehicle (virtual test)

3. Design model of the railway vehicle digital prototype-take bogie for an example

In the virtual prototyping, the first is to get the virtual prototype model which must rely on three-dimensional CAD software. How to get the virtual prototype model fast and accurately is the basic part for speeding up product design. According to the parts that can be parameterized, prototype model automated design ideas and methods are proposed. Take the bogie design for an example, this approach is detail studied. The following process of this method is shown in Fig. 2-9.
Around the bogie design automation, its implementation framework is shown in Figure 3-1. In object-oriented development environment, the automatic design of the bogie parts with user-friendly interface is completed, the data management library is established, and the changes and assembly of the bogie vehicle model (mainly for the wheelset and spring components) are implemented. At the same time, the extraction of bogie performance attribute parameters is completed, generated bogie model is saved as sel-definied file automatically, and the bogie component model and corresponding data are reproduced in the file browser. Thus, the data for dynamics calculation platform and finite element analysis platform are subsequently provided.

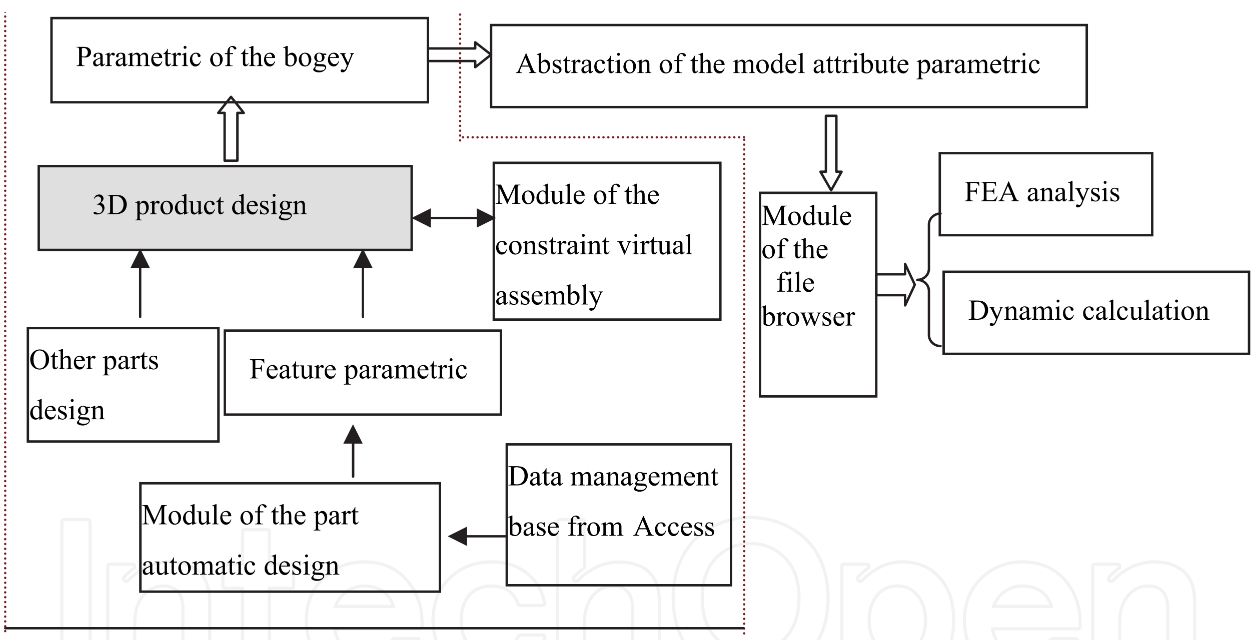


Fig. 3-1. Structure graph of the system framework

Since there are many parts in the bogey, the secondary stiff spring is taken here for an example. First, the basic design flow is obtained according to the design requirement. According to the design results, based on the technical support of COM component interface, API, CAD environment and database under three-dimensional CAD re-development environment, drive 3D rendering engine and draw out different specification three-dimensional model of the secondary stiffness spring to get the virtual model. The design results are shown in Fig. 3-2.
With the same process, other parts of the bogie can also be designed. 3-D figure of the wheelset and wheel axle which was obtained from automatic design is shown in Fig. 3-3 and 3-4.

The automatic assembly process of the bogie is shown in Fig.3-5 (some small parts omitted). Through this automatic process, it only takes less than one minute to complete bogie assembly in SolidWorks. With the parameters of the previous parts, a different type of bogie can be designed easily which speeds up the design rate and efficiency.

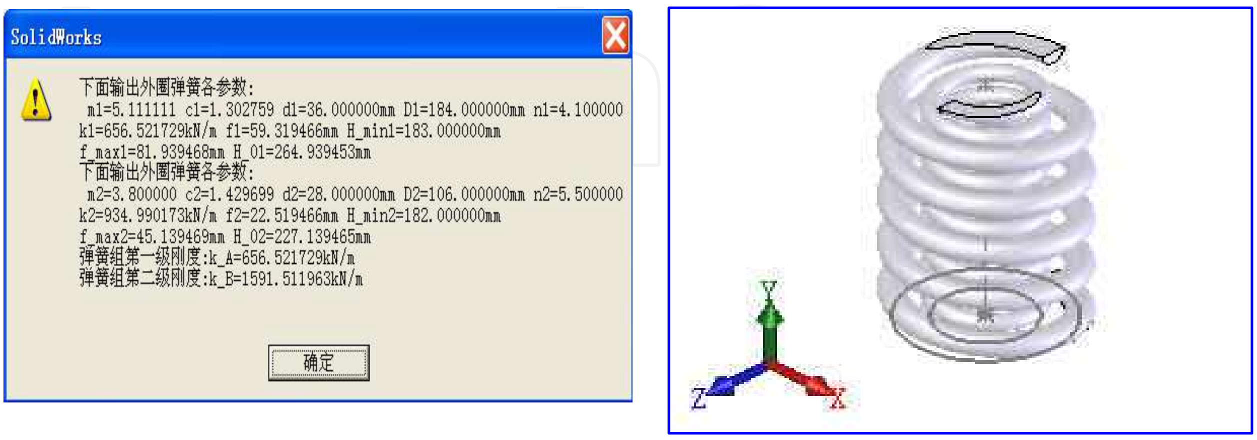


Fig. 3-2. Design automation of the secondary stiffness spring

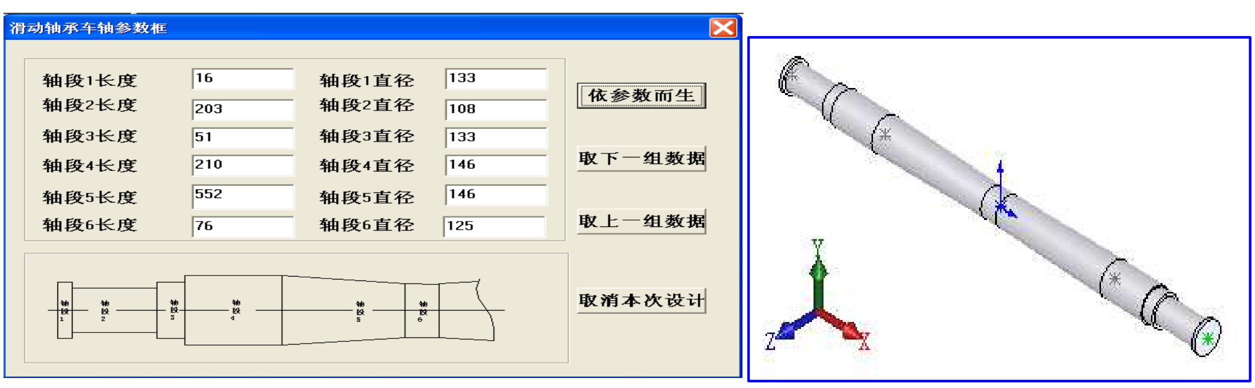


Fig. 3-3. Design automation of the axle

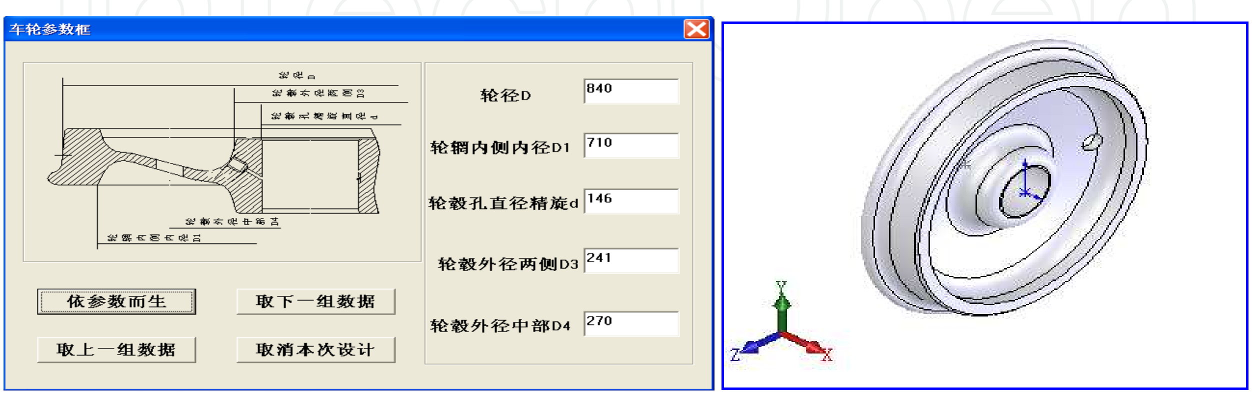


Fig. 3-4. Design automation of the wheelset

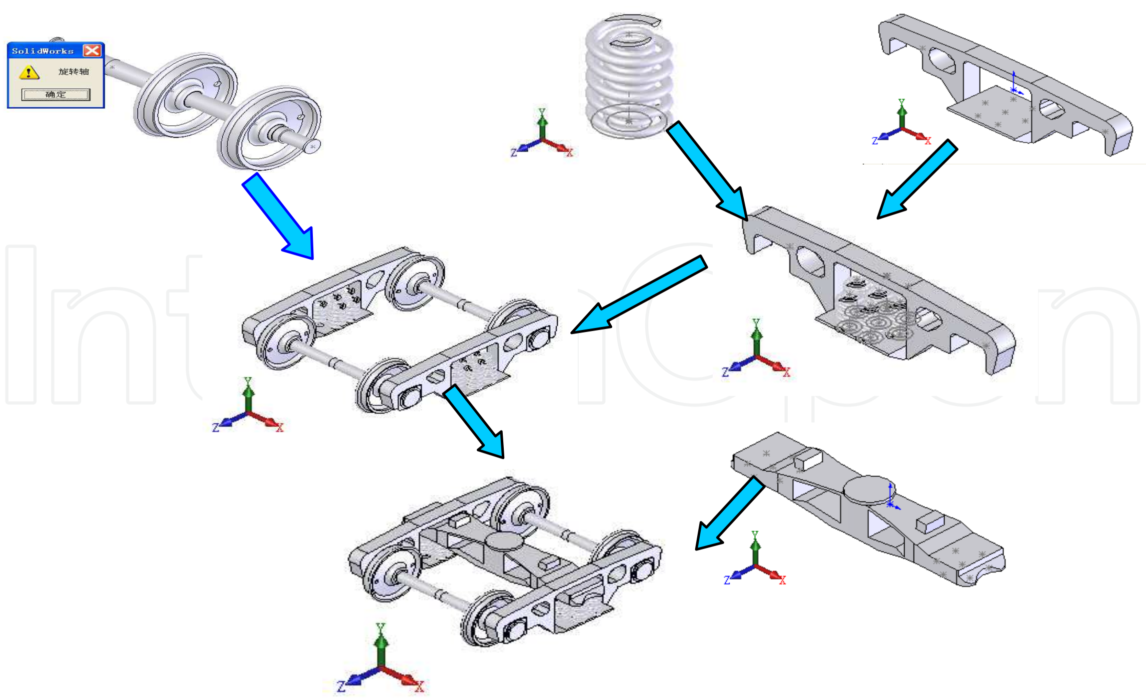


Fig. 3-5. Automatic assembly process of the bogie

4. Performance extraction of railway vehicle digital prototype oriented multi-body system

4.1 Method

Existed CAD software has been able to get a very complete product configuration and can get the relationship between the product and components in its design space, but it is mainly designed for manufacturing. Therefore, functionality and output data provided by CAD rarely faces to the subsequent performance analysis which has been confirmed in the analysis of many product cases. In the subsequent product performance analysis which includes multi-body dynamic analysis, strength and reliability analysis and other performance analysis, CAD still only provides a preliminary physical model which can not get its own performance properties from the entity itself. So the attribute data of product components need to be obtained by physical experiment. The difficulties of data collection, the investment of testing equipment and the cost of product development are enlarged. Moreover, with the perspective of practical effect, in the following process of passing the performance analysis function, due to precision, algorithm, solving model and other reasons, CAD models will lose some information that may lead to too much human intervention and waste a lot of human and material resources. Even a small mistake can result in the fact that the prototype analysis can not keep going normally. So, a lot of virtual prototype analysis at present still do their own studies. CAD is only responsible for the design. The model is re-modeled after being simplified according to the product function in dynamic analysis. The model is carried out according to the initial design scheme in finite element analysis. So these lead to serious gap between analysis software and CAD, also lead to no unification of the analytical results from different analysis software. Enterprise even does not know which algorithm is correct, so they still choose the conservative design approach such as raising the safety factor and so on. This makes people misunderstand the virtual prototyping technology.

The real reason for this misunderstanding is only considering the geometric modeling in the CAD, but not considering modeling of product components and the full machine. By putting the extraction of the product model's performance data in performance analysis module artificially, the integrity of the CAD model itself is ignored. In fact, the product CAD model provides geometric model and physical properties of the products and components simultaneously, so the physical properties should be modeled in CAD and property definition should be considered in CAD design to provide a complete integrated model for the following performance analysis which will unify the model. These two ideas are summarized in Fig. 4-1.

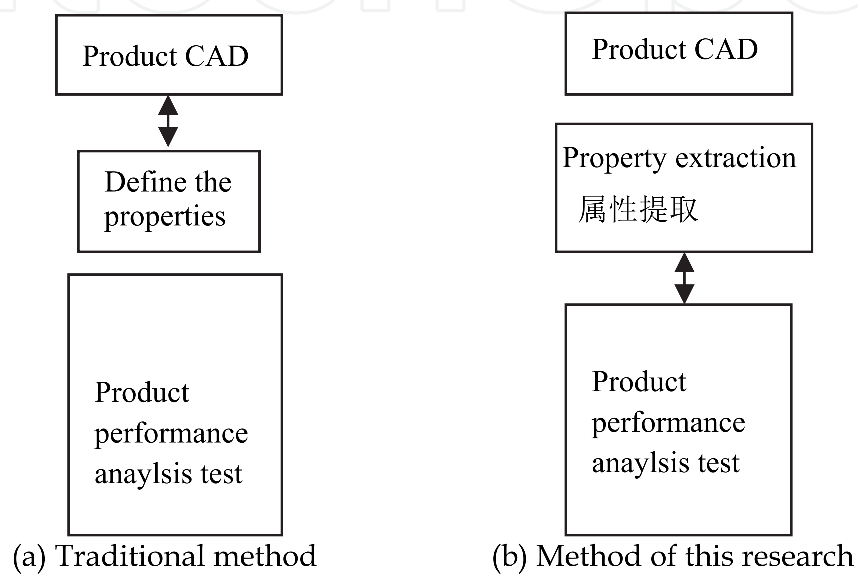


Fig. 4-1. Two different methods to definite the property

The proposed method provides an abstraction layer between CAD and prototype performance analysis in order to obtain a satisfactory virtual prototype model.

4.2 The requirements of virtual prototype model for product performance analysis under multi-body system

The ultimate virtual prototype not only depends on the completeness of the design, but also depends on the correctness of prototype analysis, which will replace the product physical prototypes to achieve product performance analysis, testing and evaluation. For mechanical system virtual prototyping, the main performance analysis tools are: strength analysis, life prediction, multi-body dynamics, fluid analysis (gas, fluid dynamics) and so on.

The basic data of the analysis are from the three-dimensional CAD design itself. Take multi-body systems analysis for example, the following performance data should be provided by the system:

For rigid body: identification number, quality, geometry shape, mass center, moment of inertia, location coordinates, position coordinates, degree of freedom, material density, etc.

For kinematic pair: identity, type, location of hinge points and associated two rigid, position coordinates of the hinge point, location coordinates of the hinge point, the number of degrees of freedom. In general, kinematic set are: rotating set, sliding set, planar joint, cylindric pair, cardan joint, spherical pair, gear pair, etc.

For the elastic body: identification number, quality, geometry shape, mass center, moment of inertia, location coordinates, freedom, material density, modulus of elasticity, mode, damping, etc.
For element force: serial number, coordinate position which connects two rigid bodies (location of the up and down points), physical definition of the force element type (stiffness, damping, friction and other characteristics).
The data are given by their own characteristics of the product components such as quality, geometry shape, mass, inertia, density, modulus of elasticity, stiffness, damping, etc. Some are obtained from product assembly relationship and space movement characteristics such as: position, location, connection relationship of hinge and multi-body, position coordinates. Many of these properties can be extracted from the CAD model, but all current CAD systems do not provide this function. So the building of an abstraction layer between CAD and prototype performance analysis is proposed to obtain a satisfactory virtual prototype model as shown in Fig. 3-6.
In theory, the second defined data is directly from the CAD design model. It should be more accurate and more reasonable, but the difficulty of CAD may increase. If taken as a separate function layer designed by design and analysis staff, this difficulty can be simplified. In the first approach, manufacturing are mainly considered after the CAD model is designed, without considering the definition of products and component attributes. Most are obtained by analyzing the functions supplied by analysis tests tools to do re-modeling.

4.3 Virtual prototype performance design solutions based on CAD

From Fig. 4-1 (b), in order to achieve the aim of extraction from CAD directly or attributes definition, higher requirements are needed on CAD functions. However, the current CAD can not meet this requirement obviously, so its function should be extended. For a variety of CAD software, they have re-development functions, such as ToolKit of Pro-E, SDK API (Application Programming Interface) of SolidWork, SDK (Software Development Kit) of CAXA. This study is based on three-dimensional CAD of CAXA.
Prototyping can be obtained from three-dimensional solid model design, Extend Data Object (EDO), internal and extended Catalogs (a pixel classification function of CAXA software) and the second development. The model attribute definitions can be defined through an external interface or SDK development of CAXA platform to obtain an extended IGES file. The so-called extensible IGES files are to keep the original model data interface and format unchanged, increase the special format data in the end of the file system which is mainly used to define the properties of the model data. This file can interface the common application software and can be used for the system which has both specialization and generality. Therefore, the obtained data are data blocks based on IGES that can describe model properties. Those data blocks form the whole data model are for the platform.
Obviously, the prototype model is actually a combination of a space abstracted physical prototype and the entity model. Entity model is obtained from the CAD design and attached to the physically abstracted model. The abstracted model not only defines the properties of the product components, but also maps to the graph-like model structure according to their functions and relationships, reducing the functionality according to the follow-up requirement. In order to overcome the model data consistency, several key issues must be solved, and they are: define and extract the data directly in the solid

model, mesh finite element in the solid model automatically in accordance with the requirements of FEA, extract model directly to do visualization of functional analysis subsequently and so on. The relationship of the model and performance analysis based on CAXA is shown in Fig. 4-2.

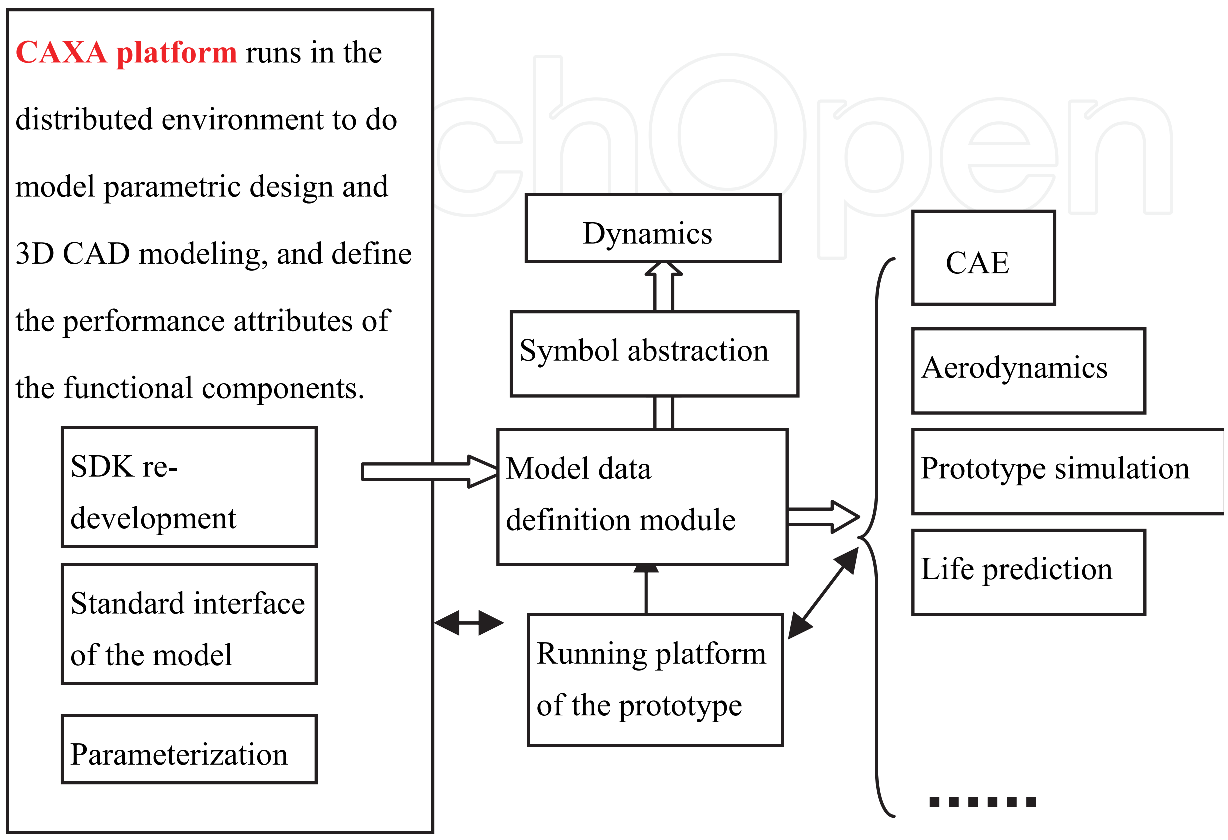


Fig. 4-2. Relationship of the model and performance analysis based on CAXA

Property definition for the performance analysis can be achieved by several re-developments such as EDO, API, Catalog and so on.

4.4 Extraction of the virtual prototype performance attribute based on CAXA

Railway vehicle system is a typical complex mechanical system. in the view of multi-body dynamics, this system is a complex system which interacts with a multi-body system. It can be simplified as: rigid body (soft body), hinge, force element, force, and etc. It can be defined as following:

1. Relative to the suspension system, the stiffness of the car, bogie, wheelset and other qualities is much great, so they can be defined as rigid body without considering their flexibility.
2. Define the suspension as force element;
3. Define the force and force couple of the rigid body as the external force.

For the body in the mechanical systems virtual prototyping, the most important is to describe its geometric and physical relationship in space. The architecture process of the performance and attributes obtained system for the entire multi-body system is shown in Fig. 4-6.

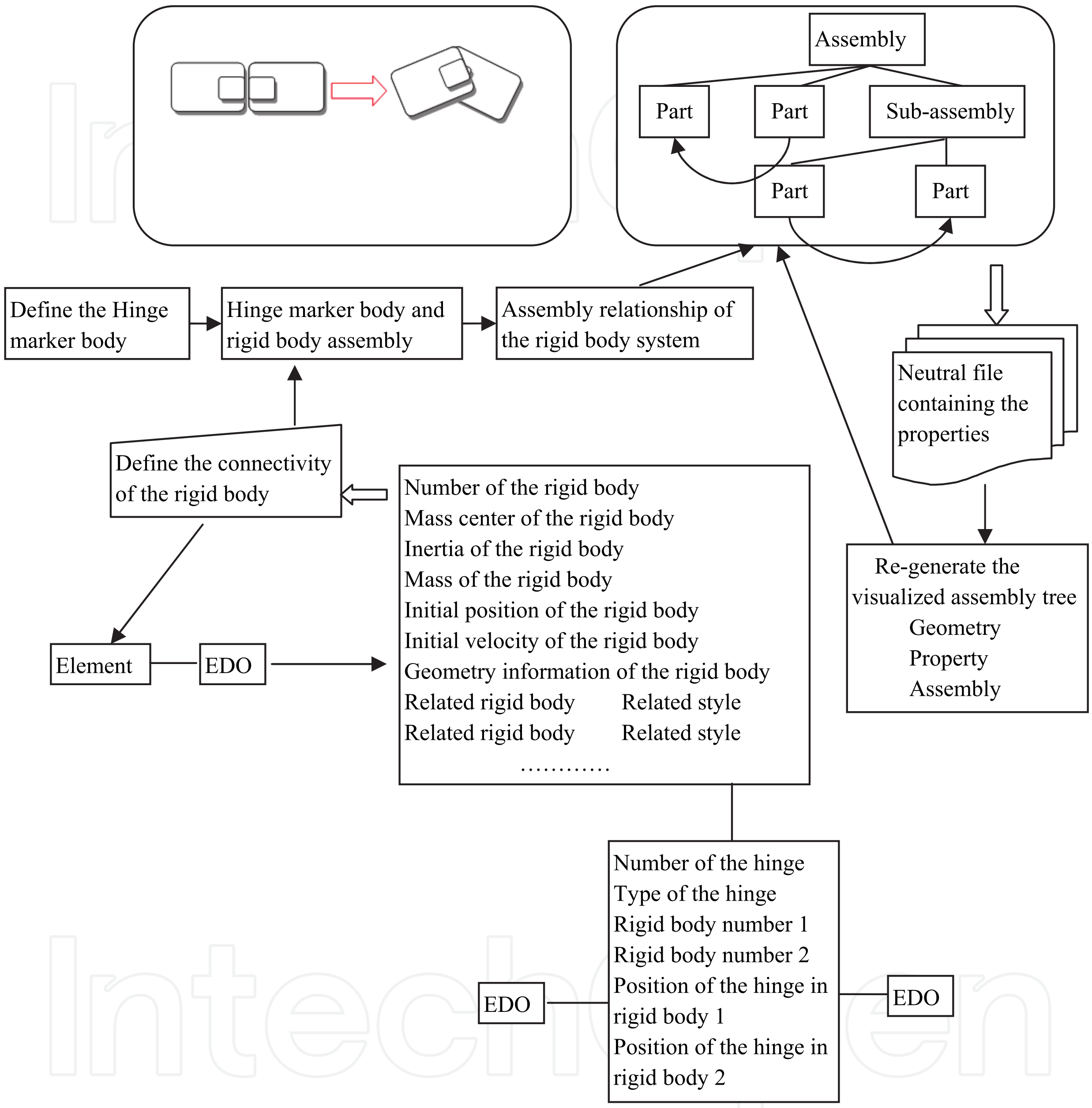


Fig. 4-6. Property extraction of the multi-body system based on CAXA

In the extracted process, coordinate transformation of design space, assembly space and feature space of the part is used in CAXA. Various properties of abstract defined bodies based on the geometric topological core are obtained. For unabstracted properties, the rich re-development interface function is used for extension, more suitable methods are: EDO, Catalog, AttributeSet, embedded database and etc.

Once the model is defined and extracted, the virtual prototype based on CAD with unified regulations and property definition can be obtained, and pass to the performance analysis module.
Physical abstracted model corresponds with entity model through the marker and serial number. It strictly reflects the space topology construct relationship between various bodies. Their mapping forms an integrated digital model which has CAD features and physical features of product components to the following performance analysis.
Property extraction in CAXA is shown in Fig. 4-8.

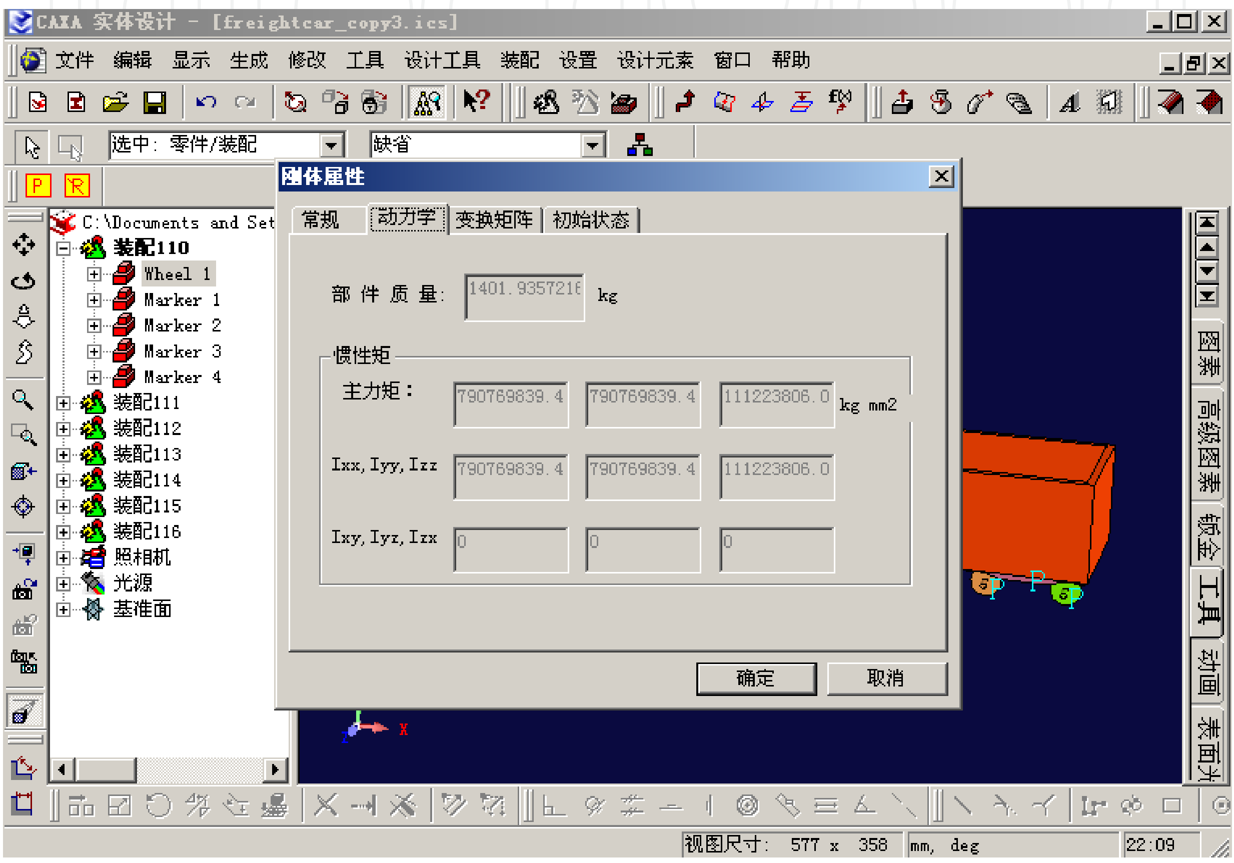


Fig. 4-8. Property extracted in CAXA

5. Topology construction of railway vehicle virtual prototype oriented to multi-body system --physical model abstraction

5.1 Transition of design prototype model to multi-body system analysis model based on virtual prototype-- the establishment of topology structure

Mapa topology structure of multi-body system in CAD environment through property modeling, and store it in a neutral file format. This format retains the defined topology of the multi-body system including assembly location relationship, position and orientation relationship of the space coordinate, constraint relations and constraint definitions between bodies and etc. Output a corresponding geometric model simultaneously which strictly corresponds to the part or assembly in the neutral file. The initial data for multi-body system modeling abstracted from the CAD modeling are obtained. The transition from virtual prototype model to the multi-body analysis model is achieved.

Decode the neutral file first. Obtain the rigid body, marker body, constraint, element force, applied force and etc according to established formats. Resume the space topology of the multi-body system according to the defined property. For example, rigid body a, b, c, has marker i, j, k, and force d, e, f, respectively, and the associated relationships ii, jj, kk, ee have been defined. The space topology structure can be resumed which is shown in Fig. 5-1.

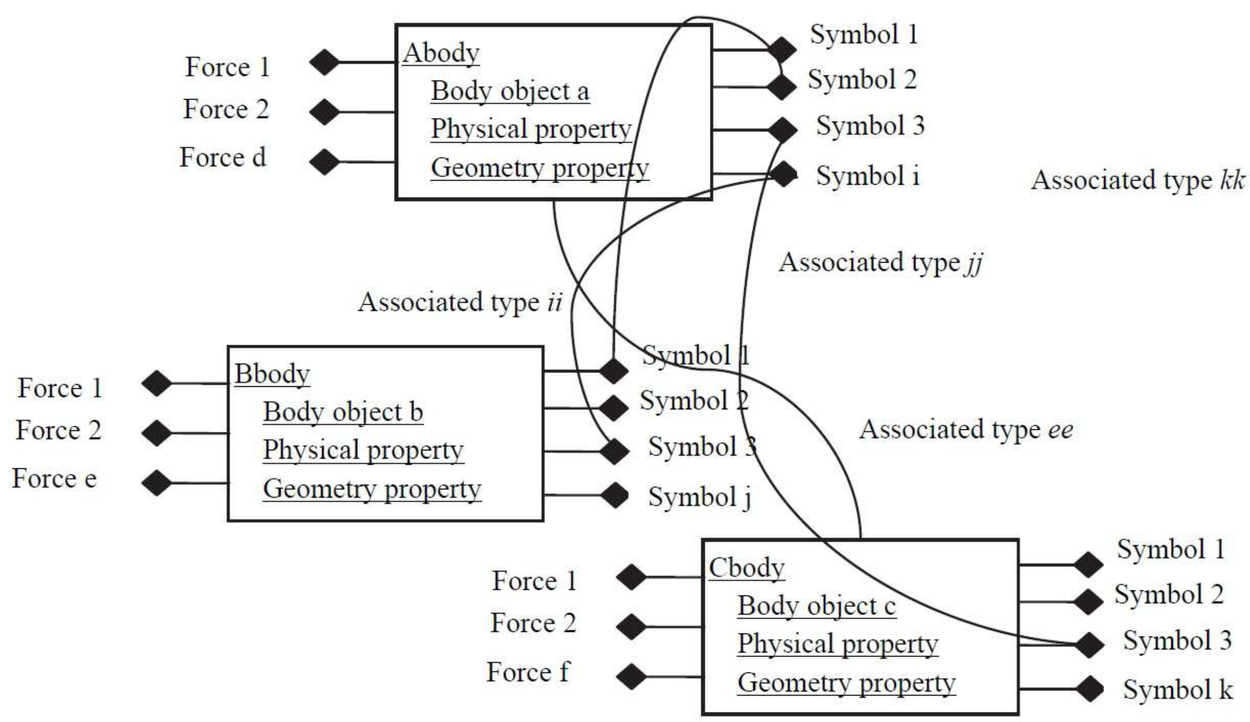


Fig. 5-1. Rebuild multi-body system structure

Although the physical models based on multi-body system are obtained, it has not been attached to the geometric solid model. In order to obtain a visual model, it needs to output the neutral file model in CAXA. In accordance with the decoded format, it can be IGES, STL, OBJ, 3DS, etc. In this study, 3DS model is adopted. The way to obtain the geometric model of the prototype is shown in Fig. 5-2.

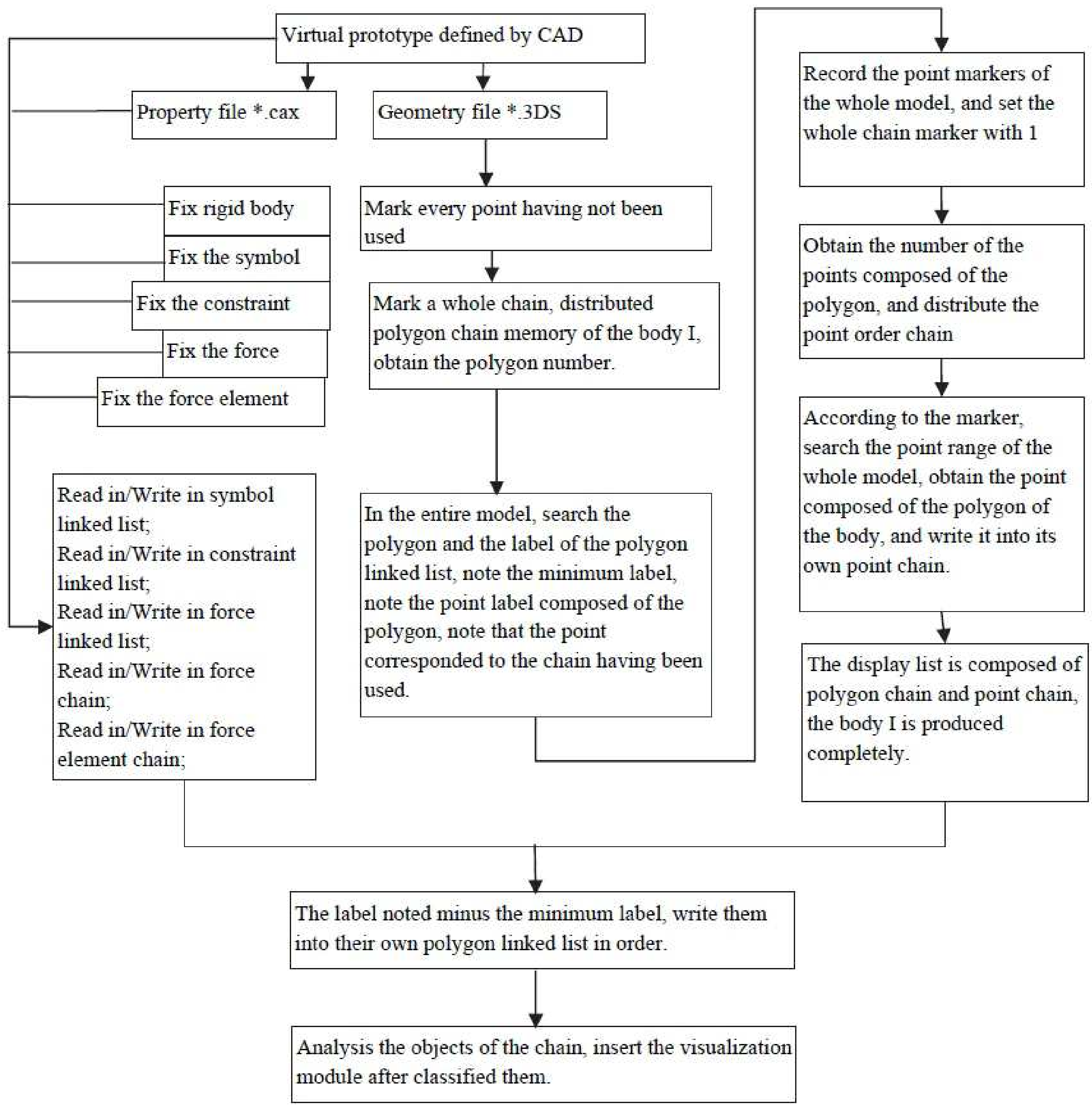


Fig. 5-2. Transition of virtual prototype of analysis model

From the figure above, multi-body description of the physical model corresponds to the objects given by geometric entities exactly. These objects determine to give which solid through classifying the point, line and surface. According to the assembly sequence of virtual prototype in CAD and marker body of the neutral file, their position relation is mapped. Properties such as transformation relation between the fixed coordinate system and the inertial coordinate system, transformation relation between the marker coordinate system and the fixed coordinate system, Euler angle corresponded to the rigid body, position and orientation of the marker coordinate system, the relationship of the defined constraints (restriction of the degree freedom), position and orientation corresponded to the force, have been strictly defined in the neutral file. Finally it is located by mapping the coordinate system of virtual prototype and space coordinate system of the visualization module to obtain the satisfactory model of multi-body system.

In accordance with the virtual prototype form CAD, describe them as objects with multi-body meaning using object-oriented idea, map them into 5 linear chains, and form a space topology model of visualized multi-body system. This model is also built on the principle of framework based on OpenGL and object oriented graphics. The existed relationship of this model in three-dimensional visualized space is shown in Fig.5-3.

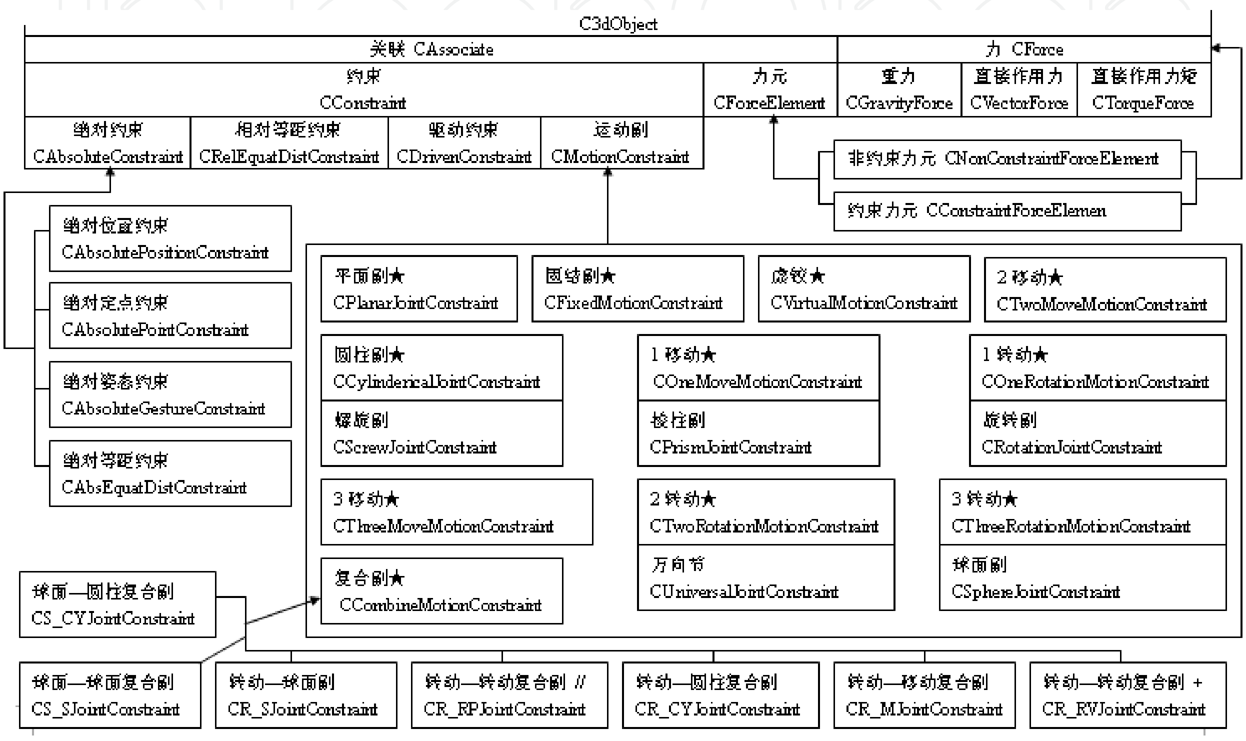


Fig. 5-3. Existed relationship of this model in three-dimensional visualized space

5.2 Topology construction of the railway vehicle multi-body system

The above visual model suits for not only mechanical multi-body system, but also railway vehicle. Considering the particularity of the railway vehicle multi-body system solution, according to the given multi-body system analysis software, the special object is established as shown in Fig. 5-4. The visualized model can be defined in the system or imported form the CAD model directly.

These objects include: Car, Bogie, Wheelset, Track, Damper, Rod, Spring and Friction plate, which complete vehicle component modeling, simulate for vehicle model running, and prepare for the dynamic calculation.

Create the solid model according to the associated sign of the given two ends. If the relative marker position changes, the shape and position or orientation of the model can be adjusted. It has basic functions of three-dimensional simulation.

Four categories have their own "dynamic" property pages. Every category has its corresponding variable receiving and data transformation which prepare initial data for dynamics solver.

Components of four categories are stress-carrying parts and are built by inheriting the CForceElement in the virtual prototype system. In order to facilitate the unified management of data, four categories created by this module are added to the CForceElementList chain, and also to the ObjectList chain for the visualization need.

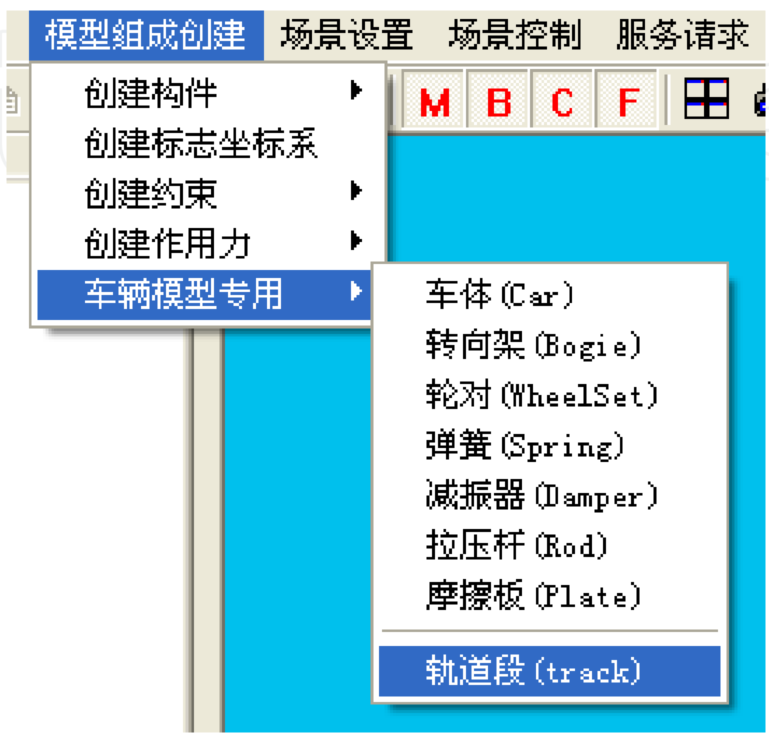


Fig. 5-4. Define railway vehicle model

Associated structure layers are shown in Fig. 5-5.

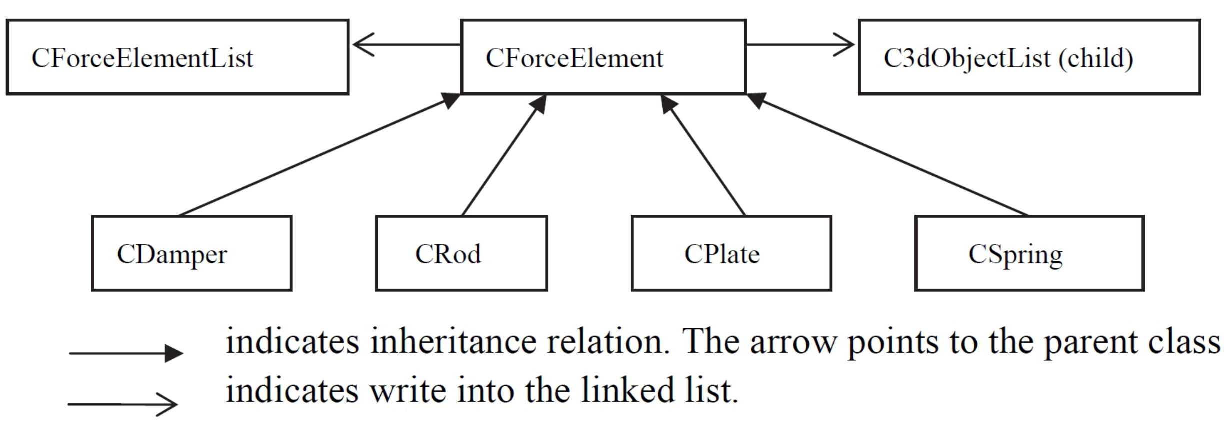


Fig. 5-5. Associated structure of the railway vehicle

A railway vehicle multi-body system model can be generated rapidly according to the above description. The defined model is shown in Fig. 5-6, which is a simplified model. Fig. 5-7 shows that import models from the design.

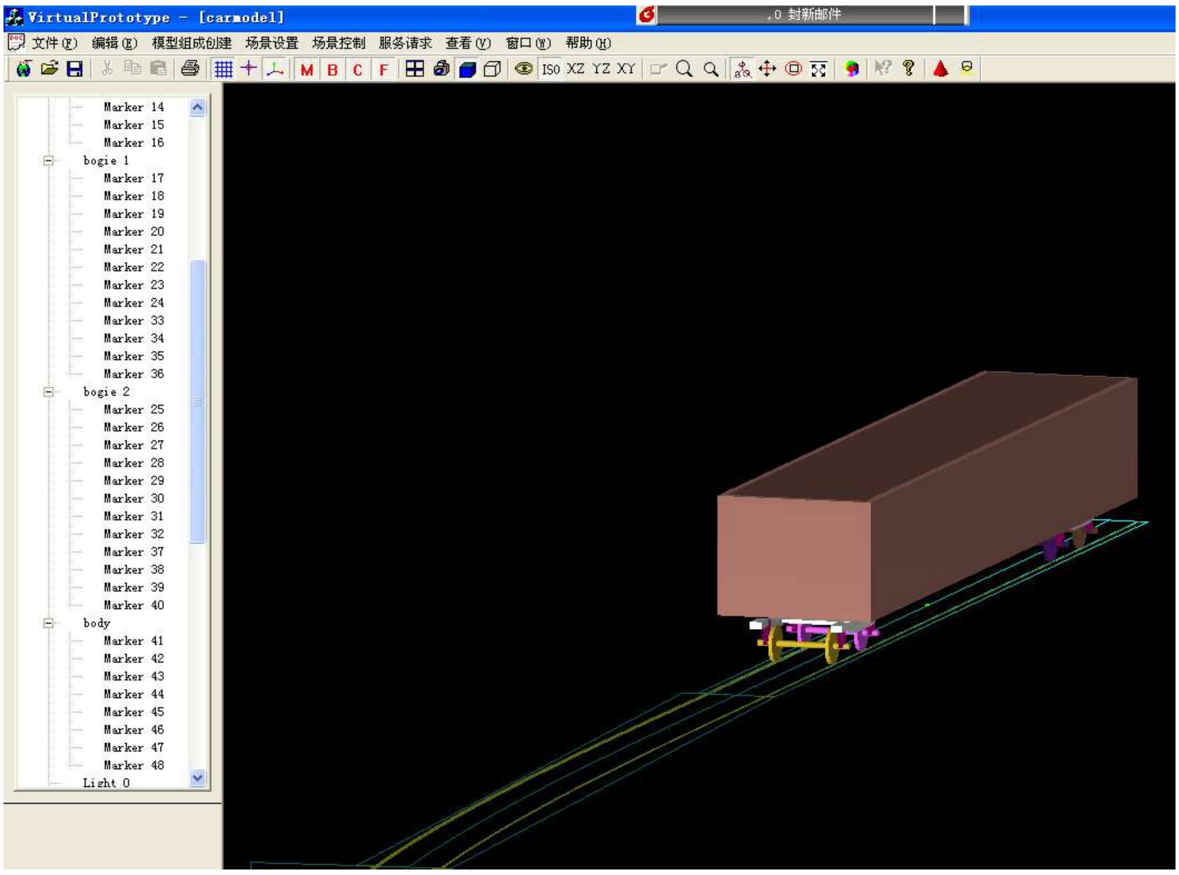


Fig. 5-6. Model the railway vehicle (simplified model, import model)

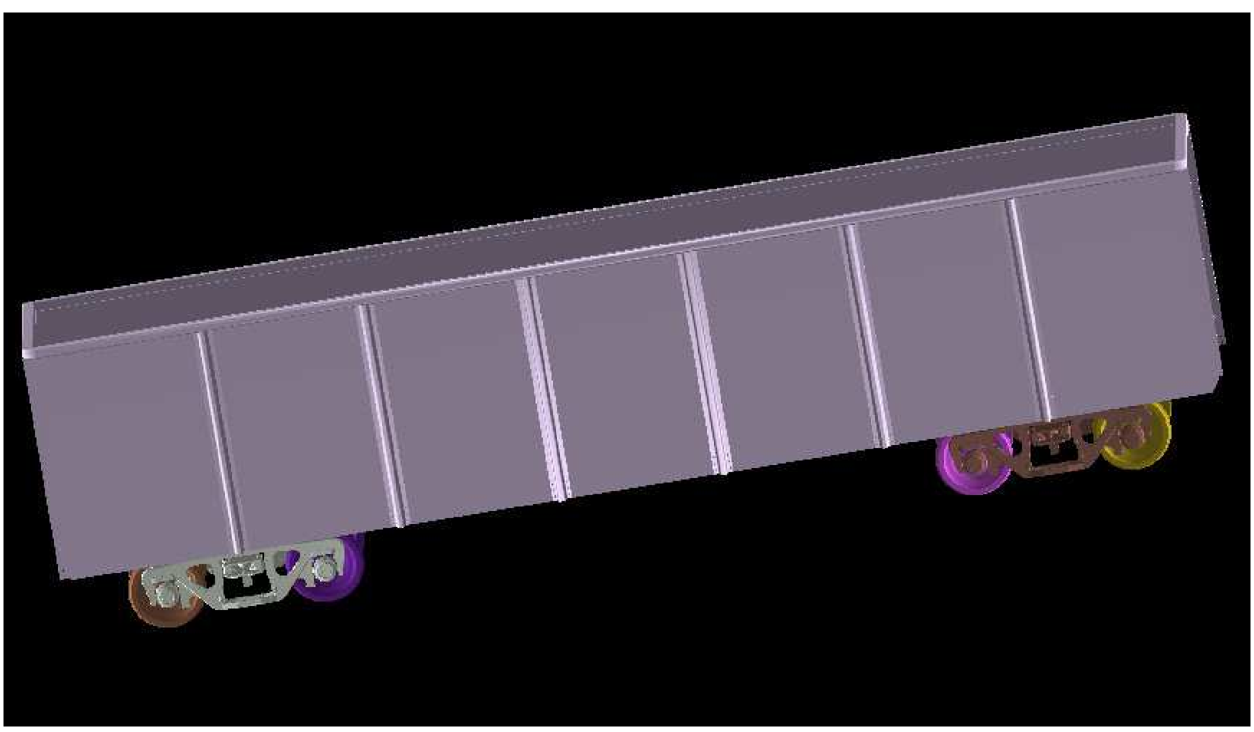


Fig. 5-7. Model the railway vehicle (obtained from the design drawing, import the model with 1:1)

5.3 Multi-body system analysis

The model established includes variety data for analysis of multi-body systems. After transiting to analysis model, multi-body analysis will be done by analysis module. Since the universality of the model and plug-in nature of the multi-body analysis module, many solvers can be used to compute for common mechanical multi-body system, such as Adams, Simpack, etc. For railway vehicle multi-body system, because of the field specialization, a specialized analysis module is needed to do analysis, such as Adams / Rail, railway vehicle part of Simpack. A software system is self-developed such as TPLdyna, VSDS. TPLdyna is developed by State Key Laboratory of Power Traction of Southwest Jiaotong Universtiy. VSDS is developed by Dr. Jue Wang of SWJTU. They both have multi-body system features but have different solvers. This study supplies the model interface to them. Here especially supports Dr. Jue Wang'VSDS, see Fig.6.10-14.

6. A case study of railway vehicle virtual prototype oriented to the multi-body system

6.1 Analysis idea

According to the modeling method above, space topology structure of the railway vehicle is shown in Fig. 6-1. B1 is car, B2 and B3 are frameworks, B4-B7 are wheelsets, B8 is track, FE1-FE6 are force elements, F1-F4 are wheel-track contact forces. Defining the force element, hinge and external force as directional has two aims: First, defining one of two adjacent objects as a reference object is to describe the relative movement of another. Second, it aims to define the positive direction of applied force and reacted force between the adjacent objects.

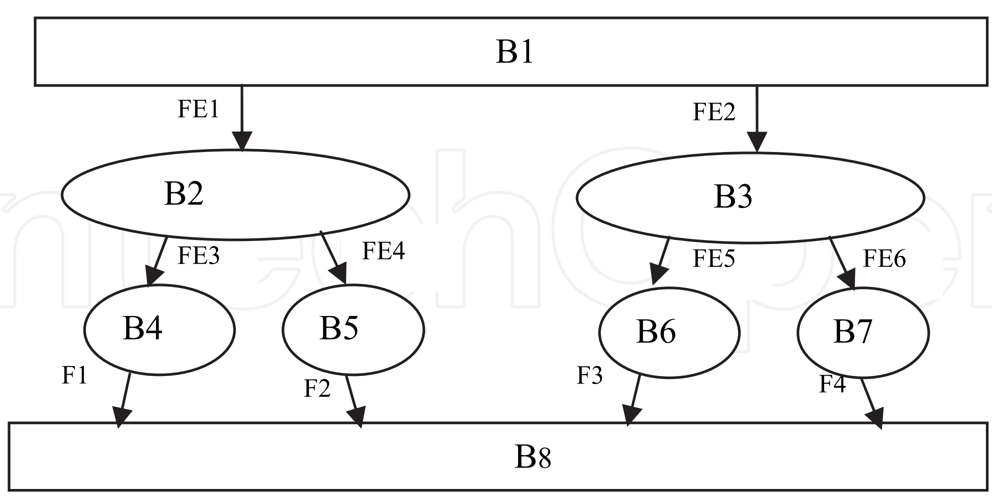


Fig. 6-1. Topology description of the railway vehicle multi-body system

To accomplish the railway vehicle virtual prototype analysis, take multi-body system analysis as an example, the processing description is shown in Fig. 6-2.

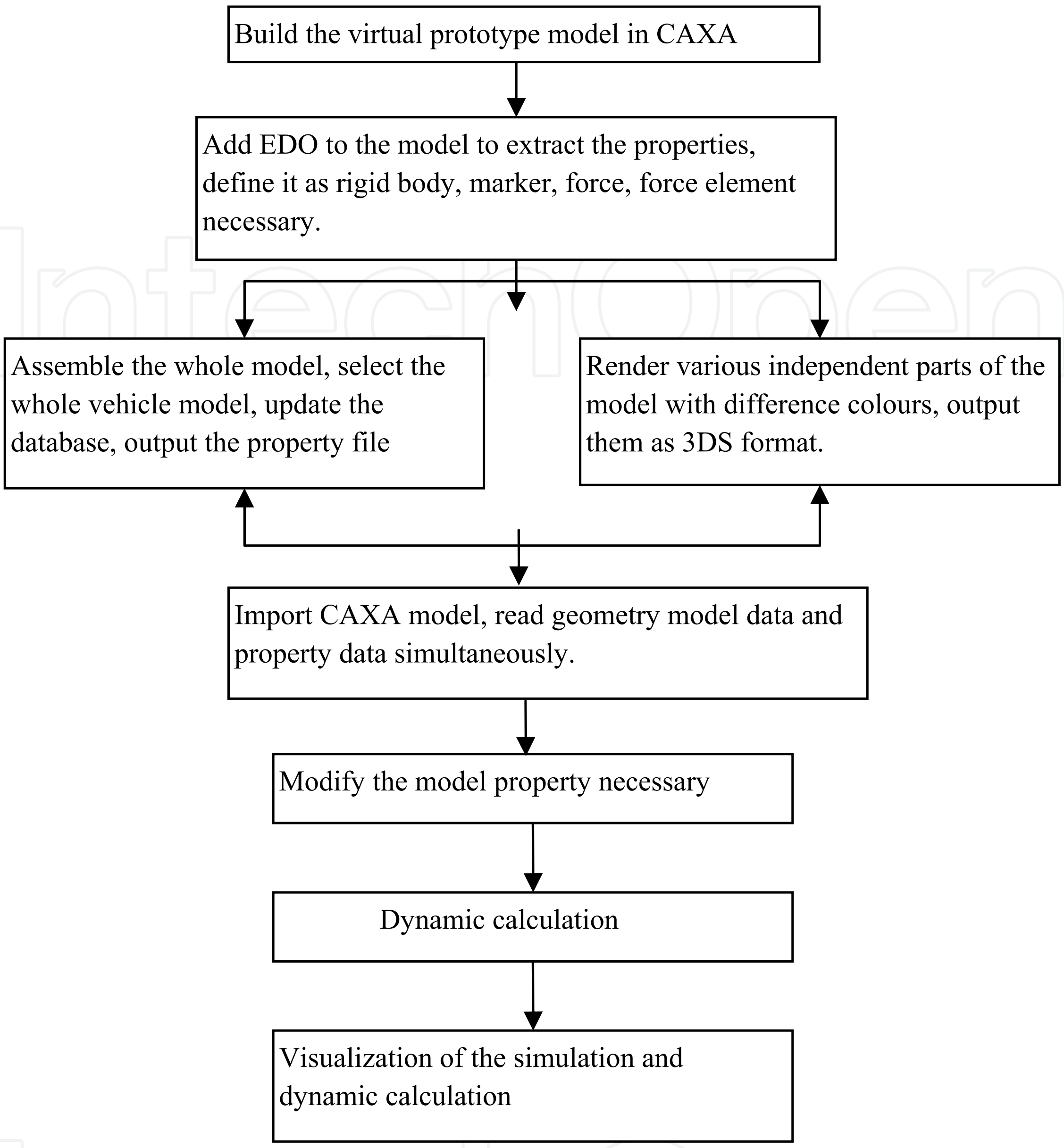


Fig. 6-2. Analysis flow of the railway vehicle virtual prototype

The process is actually obtained directly from the virtual prototype → properties extraction of the multi-body system model →transition of geometrical and physical model of multi-body systems → multi-body systems visualization modeling and mathematical modeling building → kinematics and dynamics solving of the multi-body system. This process is like mechanical system product development process, reflecting the integrated process from design model to analysis model, then to solve model, and reflecting the cycle iteration in product design process. This process supplies a theoretical and practical basis for study of product optimization process and intelligent design process.

6.2 A case process study of railway vehicle virtual prototype

Since the system is more complex, in order to obtain more significant technical route, the railway vehicle design model is simplified. The railway vehicle virtual prototype process is achieved.

1. Build the railway vehicle virtual prototype model in CAXA as shown in Fig. 6-3 and Fig. 6-4.

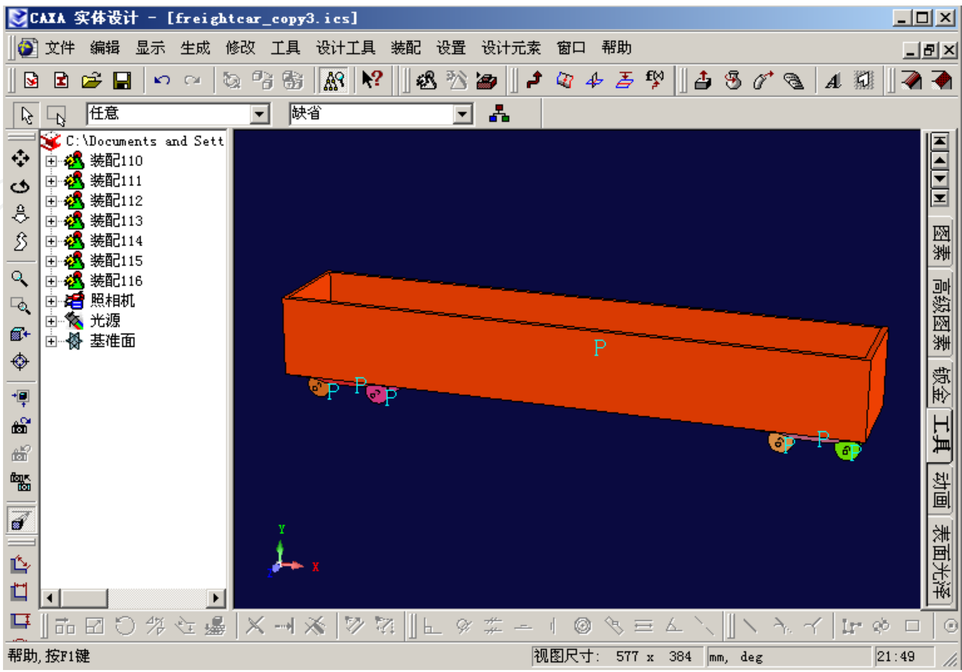


Fig. 6-3. Design model in CAXA

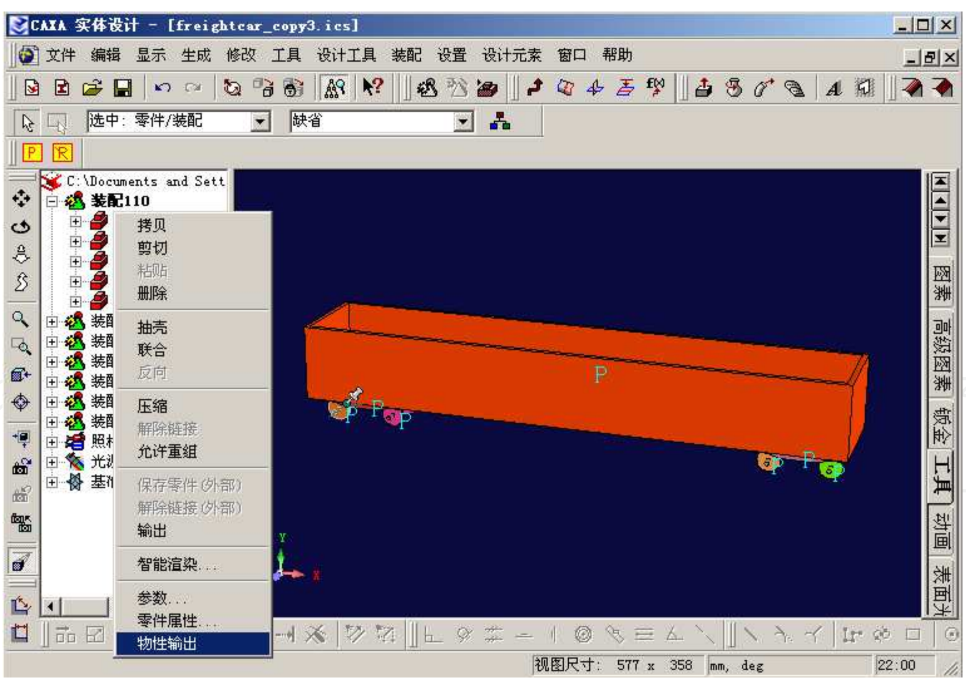


Fig. 6-4. COM interface added design model

2. Add EDO on the model to extract the model property. Then click the right key → “physical property output”, to view or add properties.
3. For components, it is required to extract attribute mass, inertia, coordinate transformation matrix, space location and etc. For initial state such as initial

displacement, velocity, etc. it should be entered manually. The physical property extraction is shown in Fig.6-5.

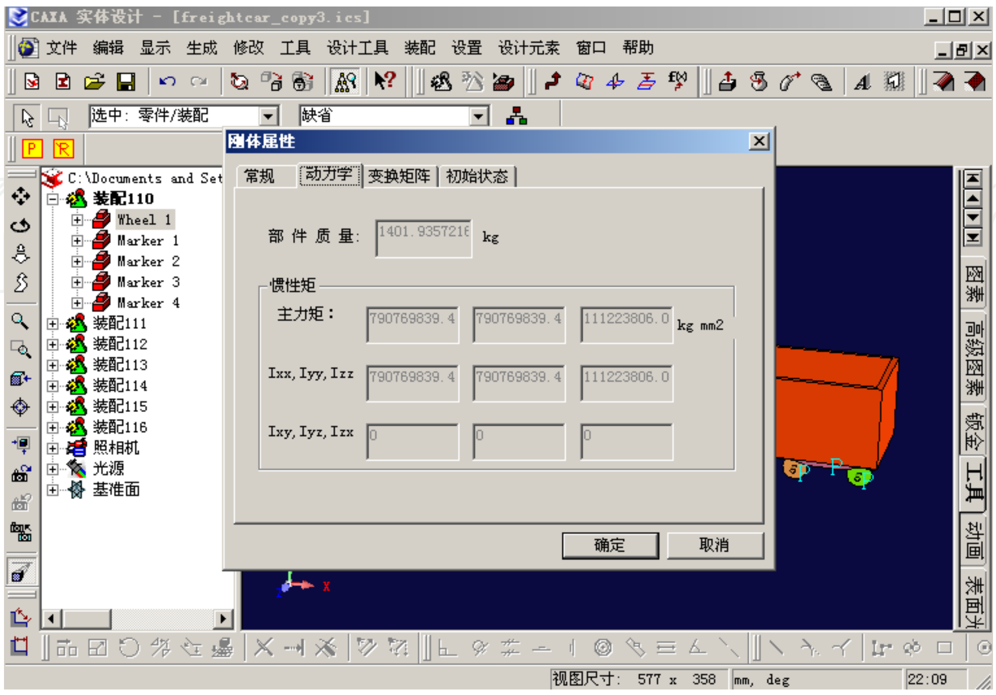


Fig. 6-5. Physical property extraction

4. For marker, the extracted information includes components, location and relative coordinate transformation matrix of the component coordinate system. Achievement of the marker information is shown in Fig. 6-6.

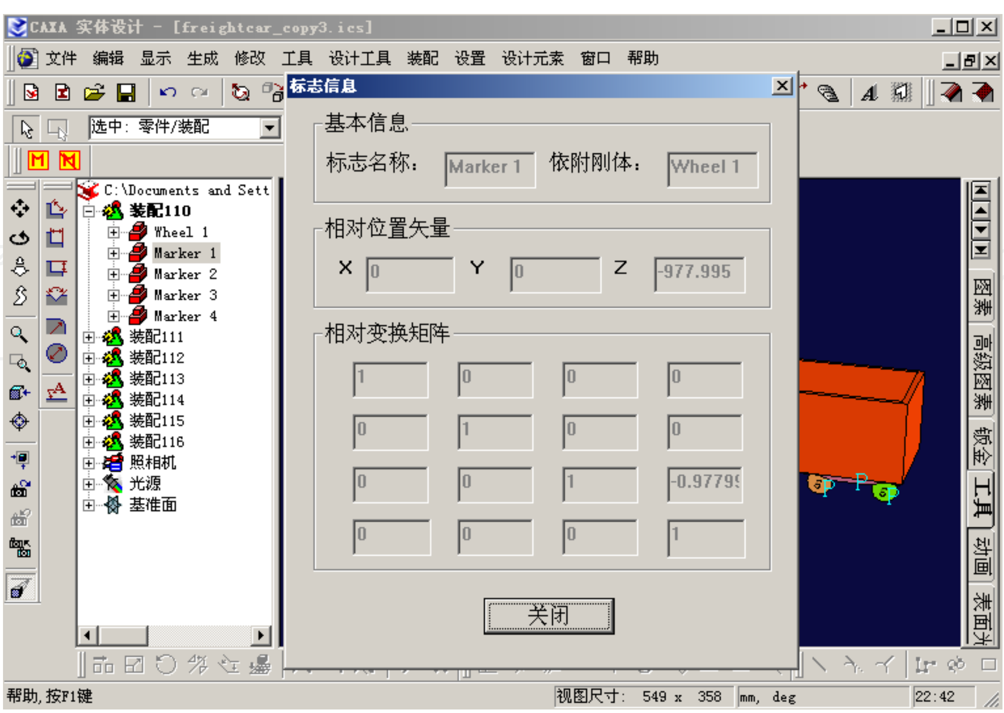


Fig. 6-6. Obtain the marker information

5. For force element (spring, damper, friction plate and rod), extracted information includes connected components and marker point which is to fix the position and orientation of the component. Multi-body topology relation from design model is shown in Fig. 6-7.

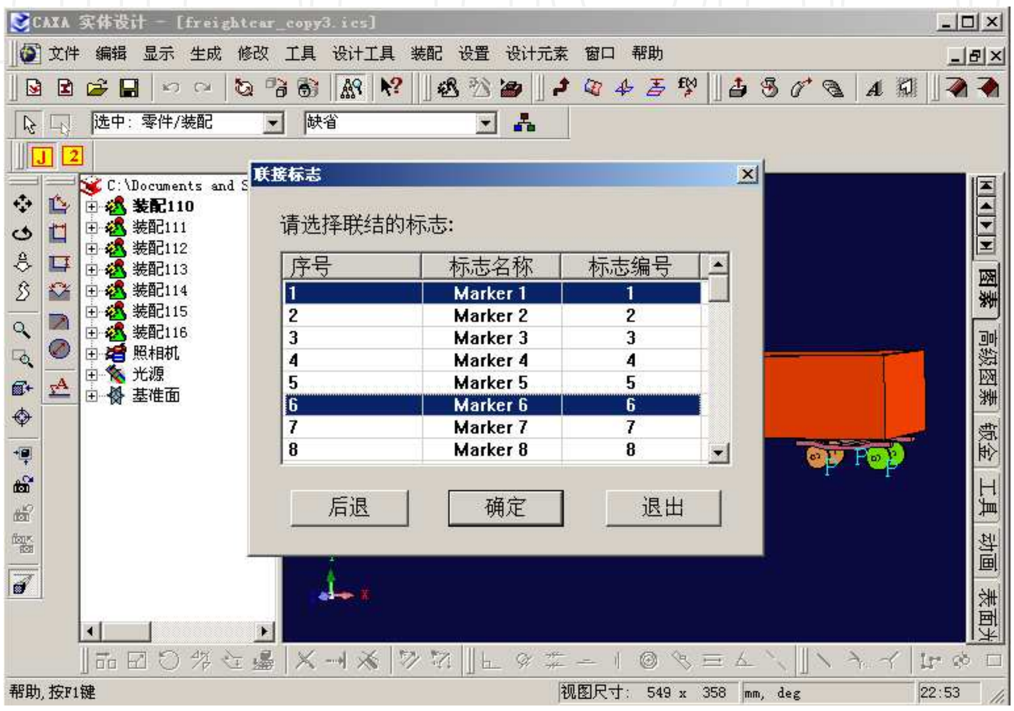


Fig. 6-7. Multi-body topology relation from design model

6. Output the property database. The extracted property has been written into the database after the operation above. The subsequent job is to assemble the whole prototype, clicking U to update the database, then clicking F to output the property data to the certain position.
7. Output the geometric model. Two points should be paid attention to:
   a. Render various independent parts of the model with difference colors.
   b. Output files as 3DS format! file name and path should be the same with property data.

By operations above, model in CAXA and property extraction has been finished.

8. Import the CAXA model and property data. The model can be recovered in VirtualMBS, and it maps the multi-body system topology relationship of railway vehicle. The catalog tree in the left clearly expresses space layer structure and mutual dependence of multi-body system. The model resuming and checking in analysis view is shown in Fig. 6-8.

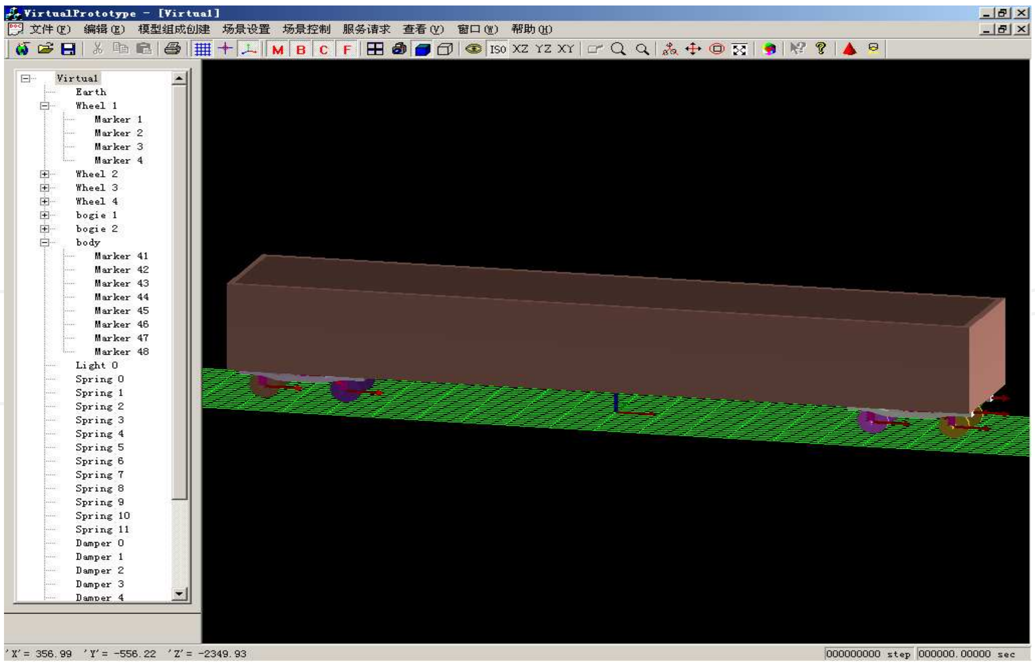


Fig. 6-8. Model resuming and checking in analysis view

9. Check the accuracy of the data imported, perfect some incomplete information. Test results show that the model is resumed completely and property data is right. The data meets the dynamics and simulation requirements. Then transition of model to performance analysis module is shown in Fig.6-9.

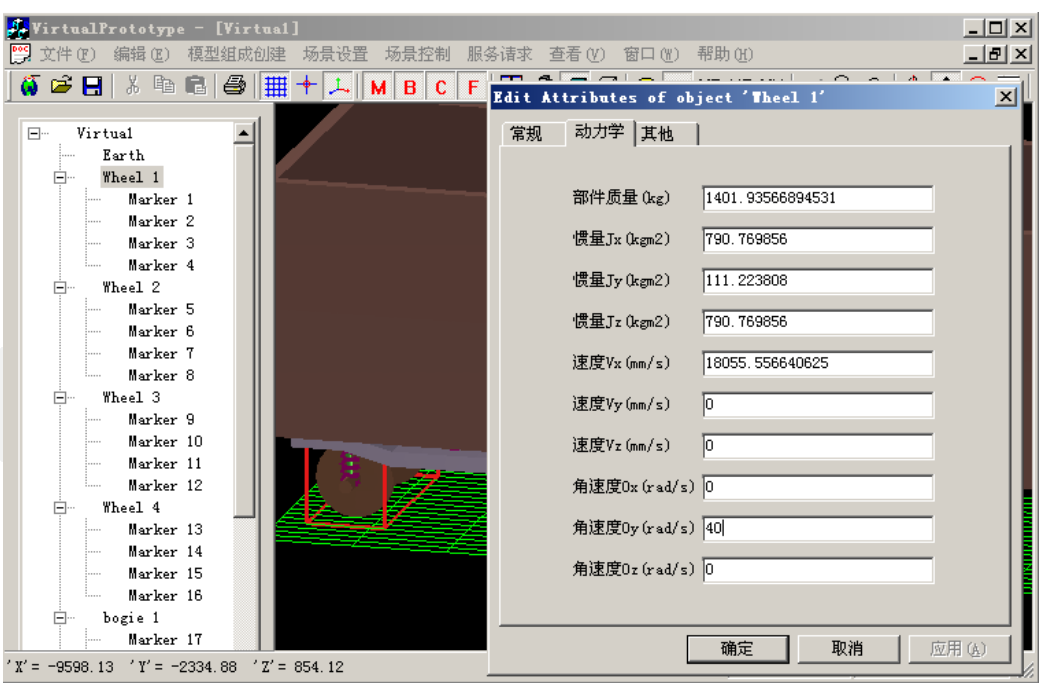
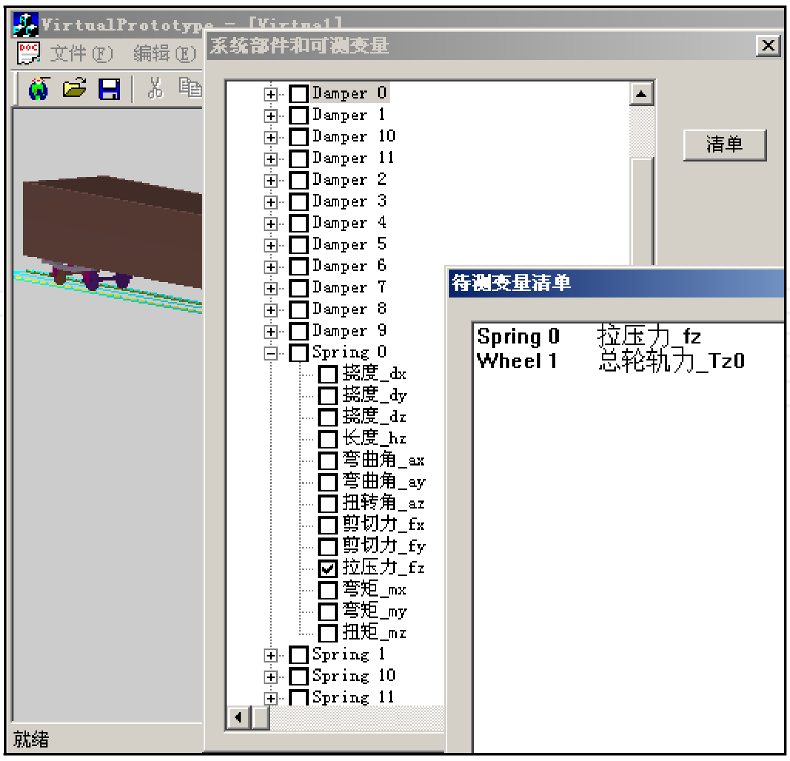
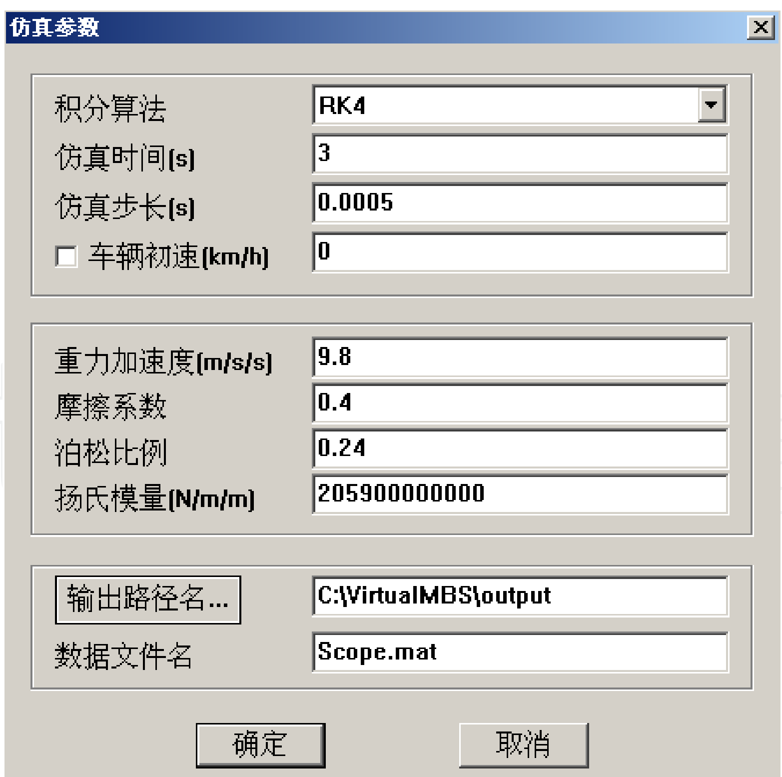


Fig. 6-9. Transition of model to performance analysis module

10. Load the track, set the measure variables and simulation parameters, and prepare for the dynamics calculation and simulation. Post-processing of the analysis module is shown in Fig.6-10.



a) Post-processing module definition of the analysis module
(two-dimensional data visualization)



b) Simulation parameter definition
of the analysis module

Fig. 6-10. Post-processing of the analysis module

11. Dynamics calculation results and simulation. Given speed is 65km/h and straight length is 30.78m, when the simulation period is 0.389s, vehicle enters the curve segment, and runs stably. Realtime simulation of the railway vehicle dynamics based on 3-D visualization is shown in Fig.6-11.

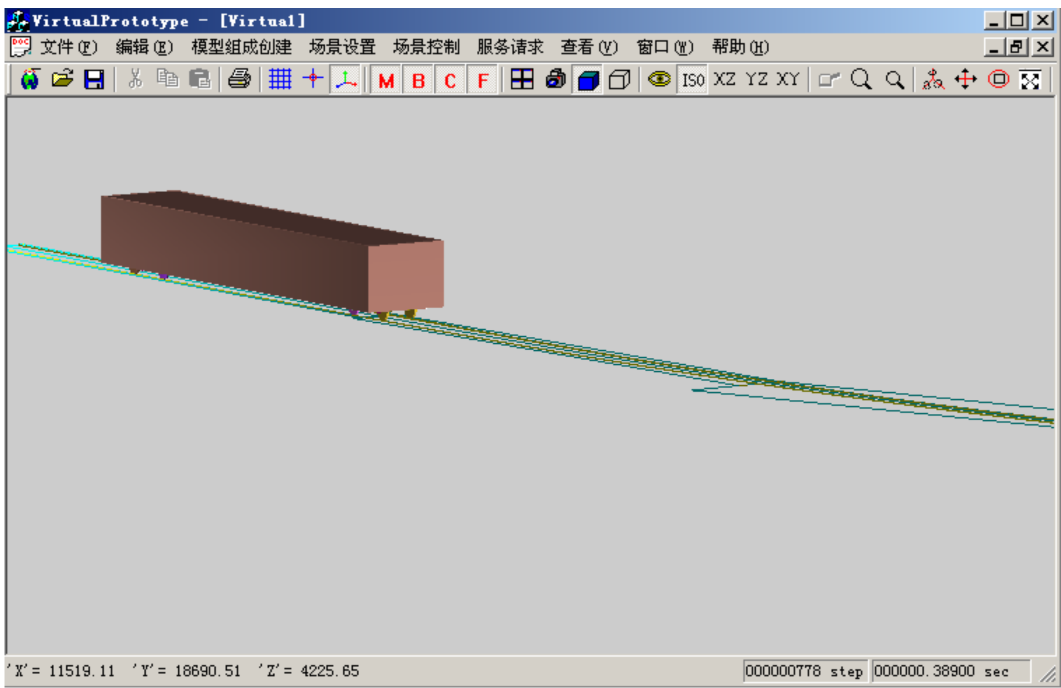


Fig. 6-11. Realtime simulation of the railway vehicle dynamics based on 3-D visualization

During the process the tension and pressure fz of the measured variable Spring0 and the total wheel force Tz0 are shown in Fig. 6-12. The red is for fz, the green is for Tz0.

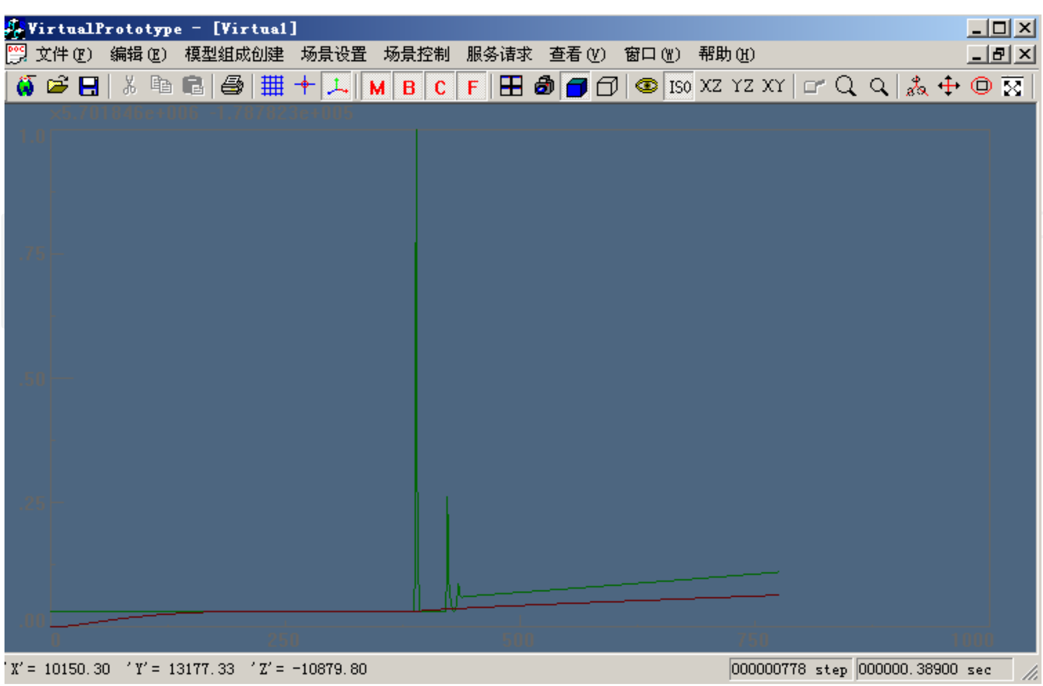


Fig. 6-12. Calculation results

Other visualized results of this system are as follows:

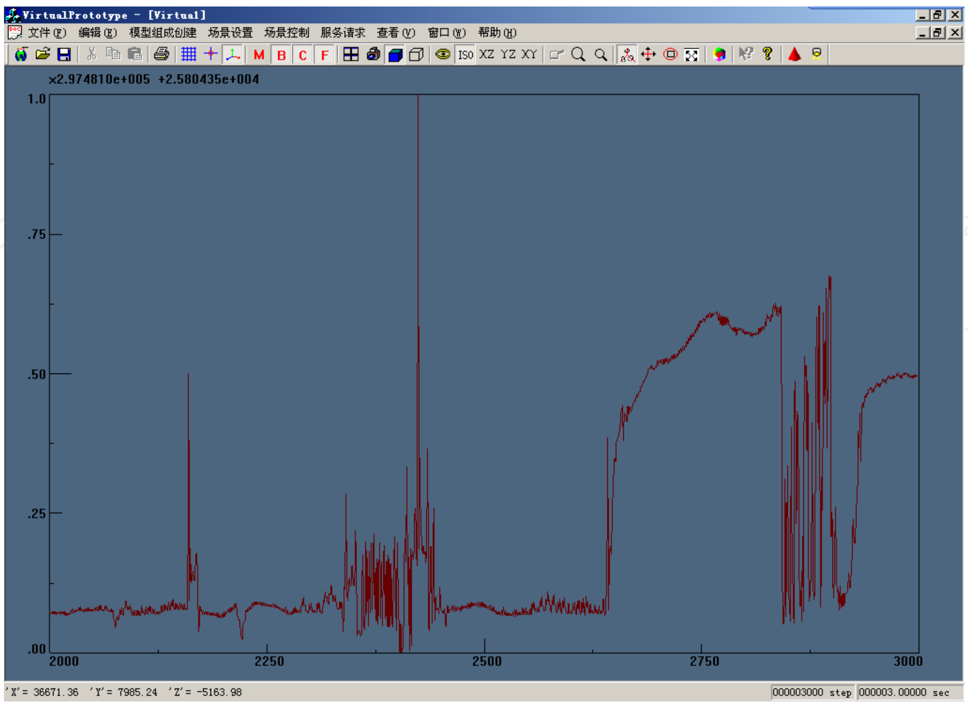


Fig. 6-13. Wheel-track force of left wheel of the wheelset 2

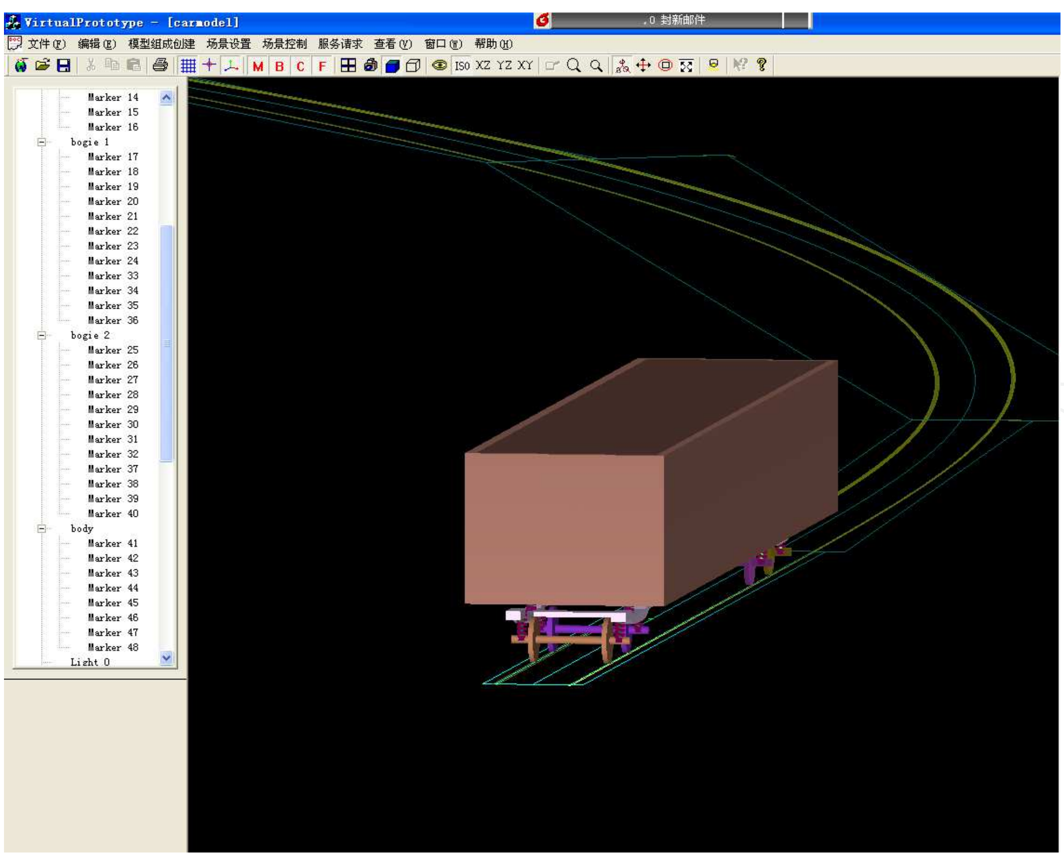


Fig. 6-14. Analysis space scene

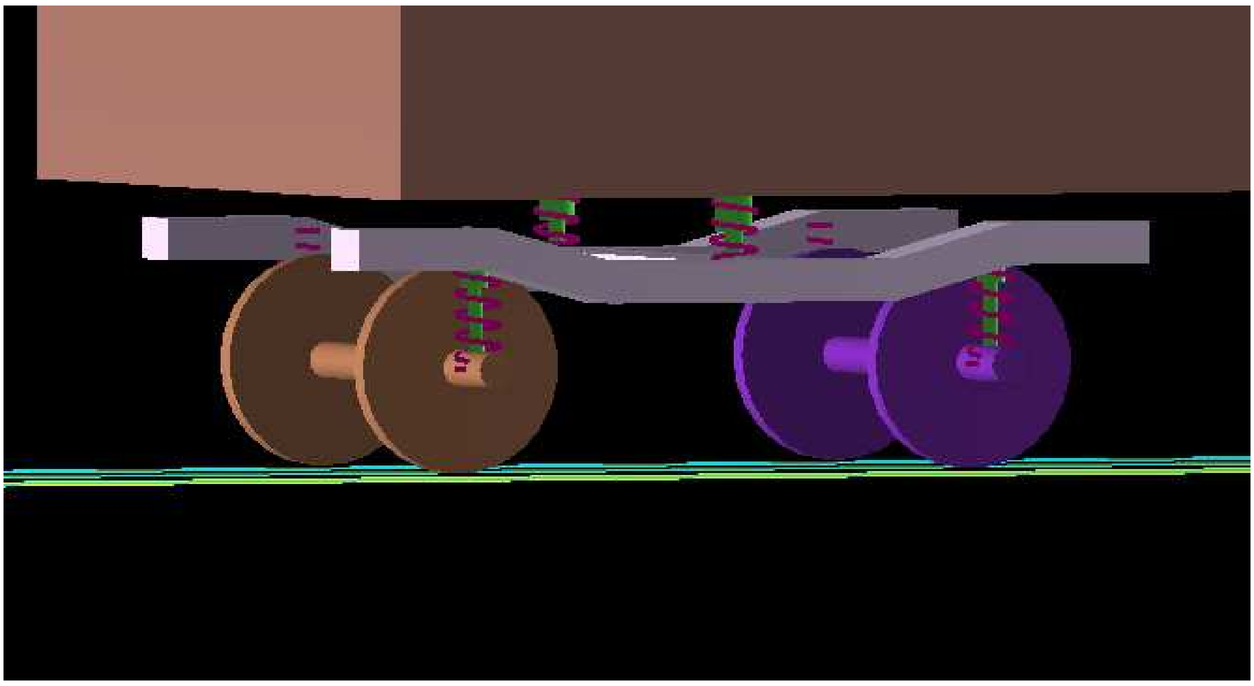


Fig. 6-15. Partial view

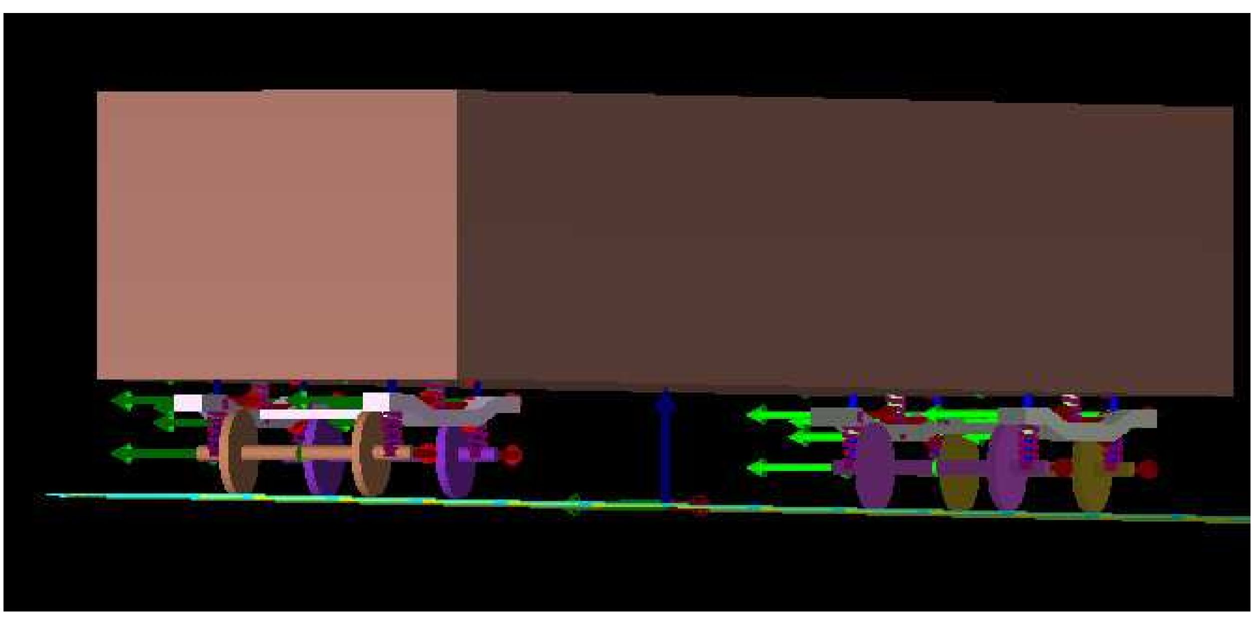


Fig. 6-16. Model with coordinate system

7. Summary

1. Through analyzing the current virtual prototyping patterns, the framework of railway vehicle virtual prototype platform is proposed.
2. The follow-up property extraction of analysis module is put into the three-dimensional CAD environment to ensure the uniformity of analysis model and prototype model.
3. The whole process of transition form prototype model to analysis model for virtual prototype is proposed and studied.
4. In order to check the series theory proposed, take a certain railway vehicle model design as an example, a case study is done in the developed software to check the research results well.

According to the study above, the technology from virtual prototype design-prototype property extraction-analysis model established based on the multi-body system-transition from multi-body system design model to multi-body system analysis model, analysis solution of multi-body system-data visualization, is initially proved, which embodies the product design process. It can be promoted to other CAE analysis module, and it supplies detailed basic research theory and techniques for railway vehicle virtual prototype platform independent researches.

8. Acknowledgment

This work is supported by the National Natural Science Foundation of China (NSFC) under Grant 50975240 and by the Youth Fund of Sichuan Province under Grant 09ZQ026-003 and the Fundamental Research Funds for the Central Universities under Grant SWJTU09ZT06, and New Century Excellence Plan Grand NCET-09-0665. In this works, VSDS computation module is used for testify the procedure, which is developed by Dr. Jue Wang. Thanks for his work.

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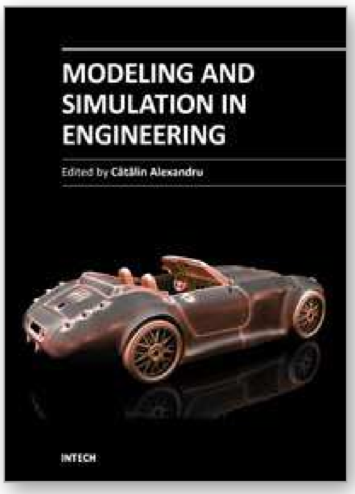

Modeling and Simulation in Engineering
Edited by Prof. Catalin Alexandru

ISBN 978-953-51-0012-6
Hard cover, 298 pages
Publisher InTech
Published online 07, March, 2012
Published in print edition March, 2012

This book provides an open platform to establish and share knowledge developed by scholars, scientists, and engineers from all over the world, about various applications of the modeling and simulation in the design process of products, in various engineering fields. The book consists of 12 chapters arranged in two sections (3D Modeling and Virtual Prototyping), reflecting the multidimensionality of applications related to modeling and simulation. Some of the most recent modeling and simulation techniques, as well as some of the most accurate and sophisticated software in treating complex systems, are applied. All the original contributions in this book are jointed by the basic principle of a successful modeling and simulation process: as complex as necessary, and as simple as possible. The idea is to manipulate the simplifying assumptions in a way that reduces the complexity of the model (in order to make a real-time simulation), but without altering the precision of the results.